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GROUND WATER POLLUTION PROBLEMS IN THE NORTHWESTERN UNITED STATES

Geraghty and Miller, Incorporated

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Frits van der Leeden, Lawrence A. Cerrillo, and David W. Miller

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*Ground water, mine wastes, salinity, septic tanks, water pollution, water quality, water resources, waste dumps, wells.

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GROUND-WATER POLLUTION PROBLEMS IN THE NORTHWESTERN UNITED STATES

by

Frits van der Leeden, Lawrence A. Cerrillo, and David W. Miller

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Project Officer

Marion R. Scalf
Robert S. Kerr Environmental Research Laboratory
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ABSTRACT

An evaluation of ground-water contamination problems has been carried out in six states in the northwest: Colorado, Idaho, Montana, Oregon, Washington and Wyoming. Ground-water supplies 12 percent of the total water withdrawn in the region, with the major pumpage in Colorado and Idaho. Industrial and agricultural growth and development of new energy sources will cause a sharp increase in ground-water use over the next 30 years.

Natural ground-water quality varies widely. Saline ground water underlies more than half of Colorado, Montana and Wyoming. In the mountainous areas, and in the more humid sections of Idaho, Washington and Oregon, the quality of ground water is generally good to excellent. The most common natural ground-water quality problems, other than high salinity, are excessive hardness, iron, manganese, and fluoride. Principal sources of man-caused ground-water quality problems in the approximate order of severity are: discharge of effluent from septic tanks and sewage treatment plants, irrigation return flow, dryland farming, abandoned oil wells, shallow disposal wells, unlined surface impoundments, mine tailings and mine drainage, municipal and industrial landfills, and radioactive waste disposal. Other sources that appear to be of less importance but still must be considered include: spills and leaks, application of fertilizers and pesticides, feedlots, and salt-water intrusion.

The findings of the investigation indicate that, with the exception of radioactive waste disposal, few cases of ground-water pollution have been investigated in detail. There is a need for baseline water-quality data and systematic evaluation of overall ground-water conditions, especially in urban zones, in areas of petroleum exploration and development, and at locations of mining and industrial activity.

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SECTION I

CONCLUSIONS

1. Total use of ground water in the six-state region in 1970 was 25.8 million cu m/d (6.8 billion gpd) of which 70 percent was for irrigation.

2. Ground water supplied 33 percent of public, 73 percent of rural, 18 percent of industrial, and 10 percent of irrigation requirements.

3. A sharp increase in ground-water use is expected in the next thirty years due to rapid industrial and agricultural growth, and the development of new energy sources from coal and perhaps oil shale deposits.

4. The major unconsolidated aquifers are in the Willamette River basin, the Puget Sound Lowland, the San Luis Valley, the South Platte and Arkansas River basins, the Spokane Valley-Rathdrum Prairie and on the Colorado High Plains.

5. Principal consolidated aquifers are sandstones; limestones and dolomites; and the basalt rocks of the Columbia Plateau and the Snake River Plain.

6. The natural quality of ground water varies widely due to differences in geologic and climatic conditions. More than half of the areas of the states of Colorado, Montana, and Wyoming are underlain by aquifers containing saline ground water. In the more humid states of Idaho, Washington, and Oregon, the natural ground-water quality is generally good to excellent.

7. The most common natural water-quality problems in freshwater aquifers are high hardness, excessive iron and manganese content, and high concentrations of fluoride.

8. The most significant source of ground-water contamination is the discharge of sewage from septic tank systems. Three million people, equivalent to one-third of the area's total population, are served by individual septic systems. Mountain home sites in crystalline rock areas with thin soil cover and on-site water wells are particularly subject to pollution of drinking water supplies from septic effluent. High septic tank density in some urban and suburban sections has led to regional problems.

9. Discharge of treated or partially treated effluent from sewage treatment plants to rivers and streams is a potential hazard to ground-water quality, particularly in semi-arid regions. Shallow aquifers in the Plains states are especially vulnerable where unconsolidated valley aquifers are in hydraulic connection with a river, and pumpage from wells induces surface water to enter the aquifer.

10. Irrigation return flow is another pressing pollution problem. A total of 6.3 million ha (15.5 million acres), representing 4 percent of the project area, is under irrigation. As of 1960, about 840,000 ha (2 million acres) were affected by salinity. Nearly 50 percent of this area was in Colorado.

11. Dryland farming in geologically unsuitable areas has caused the formation of extensive saline seeps on the northern Great Plains. The most serious problems are found in Montana, with over 32,000 ha (80,000 acres) having been affected as of 1971. Since then, an estimated additional 40,000 to 60,000 ha (100,000 to 150,000 acres) of crop land has been lost to saline seeps. A change in farming practices may be needed to control this type of degradation.

12. Well construction and abandonment procedures connected with oil and gas development are potential sources of ground-water contamination in Colorado, Montana, and Wyoming. Leaky casings, improperly cemented wells, and unplugged or inadequately plugged abandoned holes allow poor-quality water to leak into fresh-water aquifers. Each year, the oil industry drills several thousand exploratory and development wells, of which over a thousand are plugged and abandoned. Legislation regarding the sealing and abandonment of wells and test holes exists, but enforcement is lacking in many areas.

13. Brine associated with oil is usually returned to the producing formation via more than 3,000 injection wells in the states of Colorado, Montana and Wyoming. The danger lies in failure of the wells or leakage through confining zones, which would cause brine to flow into fresh-water zones. There is practically no documentation concerning ground-water contamination caused by injection of oil-field brines.

14. A few deep wells have been drilled for disposal of industrial liquid wastes and an estimated 8,000 shallow wells are used for disposal of domestic and agricultural

waste fluids. The latter pose the greater threat to ground-water quality because they typically discharge into the unsaturated zones of formations containing fresh water. Despite the large volume of waste being discharged in this manner, few serious incidents of contamination have been reported.

15. Surface impoundments used to treat, handle, or store liquid wastes and sludges are leaking large quantities of contaminants to ground water. The number of lagoons, pits, and basins is expected to increase sharply as industries change over from direct surface-water discharge to land treatment of wastes.

16. Every state in the project area has waters adversely affected by leachate from tailings piles and drainage from strip, surface, and underground mines. The industry is expected to grow rapidly under the federal government's drive for self-sufficiency in energy. Large-scale surface mining of coal on the Great Plains, mining of oil shale in Colorado and Wyoming, including new methods of removing minerals (such as underground coal gasification), pose tremendous problems to ground-water quality protection.

17. Industrial and municipal landfills are not considered a problem in the arid or semi-arid portions of the region, since little or no leachate is produced. In humid sections, leachate has been detected at many municipal landfills. Land disposal of wood wastes in Montana and Oregon has contaminated ground and surface waters with phenols and tannic acid.

18. Millions of cubic meters of low and intermediate level radioactive waste fluids have been disposed of in ponds or cribs or injected into wells at the NRTS and Hanford sites. Movement of pollutants is closely watched by the U. S. Geological Survey, using hundreds of observation wells. These waste-disposal monitoring programs are considered to be among the most closely studied cases of ground-water contamination in the nation. Large plumes of contaminated ground water are present at both sites. However, severe contamination is contained within the sites, and the degree of pollution elsewhere is below detection limits. Forecasts for various plumes are for gradual growth but reduced concentrations as a result of dilution and dispersion.

19. Spills and leaks of hazardous and non-hazardous liquids on and below the land surface are numerous. The fluids

most frequently spilled or leaked are petroleum products that are in transport or storage. Cases of ground-water contamination by gasoline spills or leaks have been documented in all six states.

20. There is little documentation regarding ground-water pollution caused by application of fertilizers or pesticides. Even in areas of heavy fertilizer use and where there is a high incidence of nitrate contamination, the degree of correlation between reported cases and amount of fertilizer applied is unknown. Most cases of pesticide contamination of ground water appear related to accidental spills in the vicinity of a well or irrigation canal.

21. There are over 2,400 feedlots in the northwest with capacities ranging from less than 1,000 to over 30,000 cattle. Documented cases of ground-water pollution due to feedlot leachate are rare, but the problem is under study by several federal and state agencies.

22. Few cases of sea-water intrusion occur in the northwest, and it has not been a major problem. Upward migration of saline water in inland areas is documented in a few areas, but no actual cases of contamination of well supplies are known.

SECTION II

RECOMMENDATIONS

1. Promote a greater appreciation of the increasing importance of ground water and the need for protection of ground-water quality on a national and regional basis through educational and informational dissemination programs.
2. Increase budgetary allocations to regulatory agencies for inventorying ground-water resources, assessing and controlling ground-water pollution, and enforcing existing regulations.
3. Develop more effective methods for inventorying existing and potential sources of ground-water contamination on a state-wide basis.
4. Expand the monitoring of suspected sources of ground-water contamination that might endanger drinking water supplies.
5. Expand the standard analyses of ground water to include a wider variety of inorganic and organic compounds.
6. Conduct additional research to develop better scientific tools to delineate the areal extent, characteristics, and fate of pollutants in aquifers.
7. Conduct basic research into economic containment and removal of various types of pollutants in aquifers.
8. Conduct further research in model simulation of stream-aquifer systems as a water-quality management tool.
9. Develop a sound scientific basis for protection of fresh-water aquifers from pollution through control of land use and ground-water diversion, taking into account geologic, hydrologic, and other environmental considerations.

SECTION III

INTRODUCTION

The current use of fresh water in the United States for all purposes except the generation of hydroelectric power is about 1,140 cu hm/d or 300 bgd. 1) Most of this water is supplied by rivers and streams, but in recent decades ground water pumped from wells has begun to play a more significant role in water supply, so that ground-water resources now furnish one-fifth of the nation's fresh-water needs and undoubtedly will provide an even larger portion by 1980, when the national water requirement will be about 2,280 cu hm/d (600 bgd). The widespread availability of ground water and its desirable properties, such as clarity, bacterial purity, and generally consistent temperature and chemical quality, have led to the present day expansion of water-well systems in the nation. Economics and land use are other factors favoring ground-water development. More and more public water-supply systems, industries, and commercial establishments, especially in densely populated regions, can no longer obtain the large tracts of land that are required for construction of new surface-water reservoirs.

Management and protection of the ground-water resources is of the utmost importance. Whereas pollution of surface-water supplies is readily detected and often quickly corrected, pollution of ground water is often not detected until a considerable part of an aquifer system has been adversely affected. Once an aquifer is polluted, it takes a very long time and great financial expenditure to alleviate the problem. Often the damage cannot be undone and the water source has to be abandoned. For these reasons laws and regulations to protect ground-water reservoirs must be adopted. National and state-wide measures to control the quality of ground water are needed, and recommendations to this effect have been made by federal, state and private organizations, including the National Water Commission. 2,3,4) Prior to devising such control measures, a full understanding of natural ground-water quality and ground-water pollution problems existing in the various regions of the nation is needed. The Environmental Protection Agency has undertaken the task of gathering this information, and reports dealing with ground-water pollution have been issued for the Southwestern States, the South-Central States, and the Northeastern States. 5,6,7)

This report deals with ground-water pollution problems in the northwestern United States, a region that includes the states of Colorado, Idaho, Montana, Oregon, Washington and Wyoming. The report is intended to give an overview of ground-water conditions in the six states and to describe and identify natural and man-made causes of ground-water pollution. It also assesses the problems and trends in ground-water quality and recommends research and control mechanisms to protect ground-water quality.

USE OF GROUND WATER

In 1970, the total fresh ground-water withdrawal in the nation was 227 cu hm/d (68 bgd), equivalent to 21 percent of all fresh water withdrawn. 1) Surface and ground-water withdrawals for public, rural, self-supplied industrial, and irrigation use within the six states of the project area are given on Table 1 and on Figures 1 and 2. As shown on Figure 1, all Northwest states are heavily dependent on surface water, and ground-water usage ranges from 4 to 15 percent of all fresh water withdrawn. Within the project area, ground-water usage was about 25.8 cu hm/d (6.8 bgd), equivalent to 12 percent of the total water use, well below the national average of 21 percent.

Public water-supply systems in the project area used a total of 6.8 cu hm/d (1.8 bgd) of water. One-third of this water was supplied from wells. The large cities of Denver, Portland and Seattle rely totally on surface-water supplies. 8) Tacoma obtains some 6 percent of its water supply from ground water. Spokane is the only large city in the project area that entirely depends on ground water. In 1962 this city obtained 257,000 cu m/d or 68 mgd of ground water from 19 wells. 8)

In the mountain areas, municipalities generally depend on surface water for supply, but numerous community water systems, especially in Montana, Wyoming and Colorado, depend entirely on ground water. For example, in Montana, of a total of 173 municipalities, 150 use ground water for supply. 9) In Colorado, of a total of 244 water-supply systems, 135 depend entirely on water from wells, and 29 other systems use a combination of surface and ground water. 10)

Rural water supplies are heavily dependent on ground water. This water is used for domestic consumption and cattle watering. Seventy-three percent of all rural water use is derived from ground water.

Industrial water, exclusive of water used for power generation, is mostly derived from surface-water sources. However, 18 percent of all water used by industry is pumped

Table 1. ESTIMATED USE OF WATER IN THE NORTHWEST UNITED STATES IN 1970. 1)

	Public Supply		Rural Supply a)		Industrial b)	
State	1,000 m^3/d	mgd	1,000 m^3/d	mgd	1,000 m^3/d	mgd
COLORADO						
Ground water	299	79	110	29	208	55
Surface water	1,173	310	61	16	492	130
Total:	1,472	389	171	45	700	185
Percent of total that is ground water	20		65		30	
IDAHO						
Ground water	363	96	121	32	1,287	340
Surface water	57	15	53	14	416	110
Total:	420	111	174	46	1,703	450
Percent of total that is ground water	86		70		76	
MONTANA						
Ground water	98	26	98	26	129	34
Surface water	322	85	64	17	454	120
Total:	420	111	162	43	583	154
Percent of total that is ground water	23		60		22	

a) Domestic and livestock

b) Saline water and water used for thermoelectric power excluded.

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHWEST UNITED STATES IN 1970. 1)

	Public Supply		Rural Supply a)		Industrial b)	
State	1,000 m^3/d	mgd	1,000 m^3/d	mgd	1,000 m^3/d	mgd
OREGON						
Ground water	254	67	606	160	416	110
Surface water	606	160	125	33	9,804	2,590
Total:	860	227	731	193	10,220	2,700
Percent of total that is ground water	30		83		4	
WASHINGTON						
Ground water	1,098	290	182	48	568	150
Surface water	2,309	610	53	14	1,552	410
Total:	3,407	900	235	62	2,120	560
Percent of total that is ground water	32		77		27	
WYOMING						
Ground water	91	24	38	10	254	67
Surface water	95	25	61	16	76	20
Total:	186	49	99	26	330	87
Percent of total that is ground water	49		38		77	
GRAND TOTAL						
Ground water	2,203	582	1,155	305	2,862	756
Surface water	4,561	1,205	416	110	12,795	3,380
Total:	6,764	1,787	1,571	415	15,657	4,136
Percent of grand total that is ground water	33		73		18	

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHWEST UNITED STATES IN 1970. 1)

	Irrigation		Total	
State	1,000 m^3/d	mgd	1,000 m^3/d	mgd
COLORADO				
Ground water	7,192	1,900	7,809	2,063
Surface water	41,640	11,000	43,366	11,456
Total:	48,832	12,900	51,175	13,519
Percent of total that is ground water	15		15	
IDAHO				
Ground water	7,949	2,100	9,720	2,568
Surface water	49,210	13,000	49,736	13,139
Total:	57,159	15,100	59,456	15,707
Percent of total that is ground water	14		15	
MONTANA				
Ground water	238	63	564	149
Surface water	28,769	7,600	29,609	7,822
Total:	29,007	7,663	30,173	7,971
Percent of total that is ground water	1		2	

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHWEST UNITED STATES IN 1970. 1)

	Irrigation		Total	
State	1,000 m^3/d	mgd	1,000 m^3/d	mgd
OREGON				
Ground water	2,385	630	3,661	967
Surface water	15,899	4,200	26,434	6,983
Total:	18,284	4,830	30,095	7,950
Percent of total that is ground water	13		12	
WASHINGTON				
Ground water	1,325	350	3,173	838
Surface water	20,062	5,300	23,976	6,334
Total:	21,387	5,650	27,149	7,172
Percent of total that is ground water	6		12	
WYOMING				
Ground water	492	130	875	231
Surface water	19,684	5,200	19,916	5,261
Total:	20,176	5,330	20,791	5,492
Percent of total that is ground water	2		4	
GRAND TOTAL				
Ground water	19,581	5,173	25,801	6,816
Surface water	175,264	46,300	193,036	50,995
Total:	194,845	51,473	218,837	57,811
Percent of grand total that is ground water	10		12	

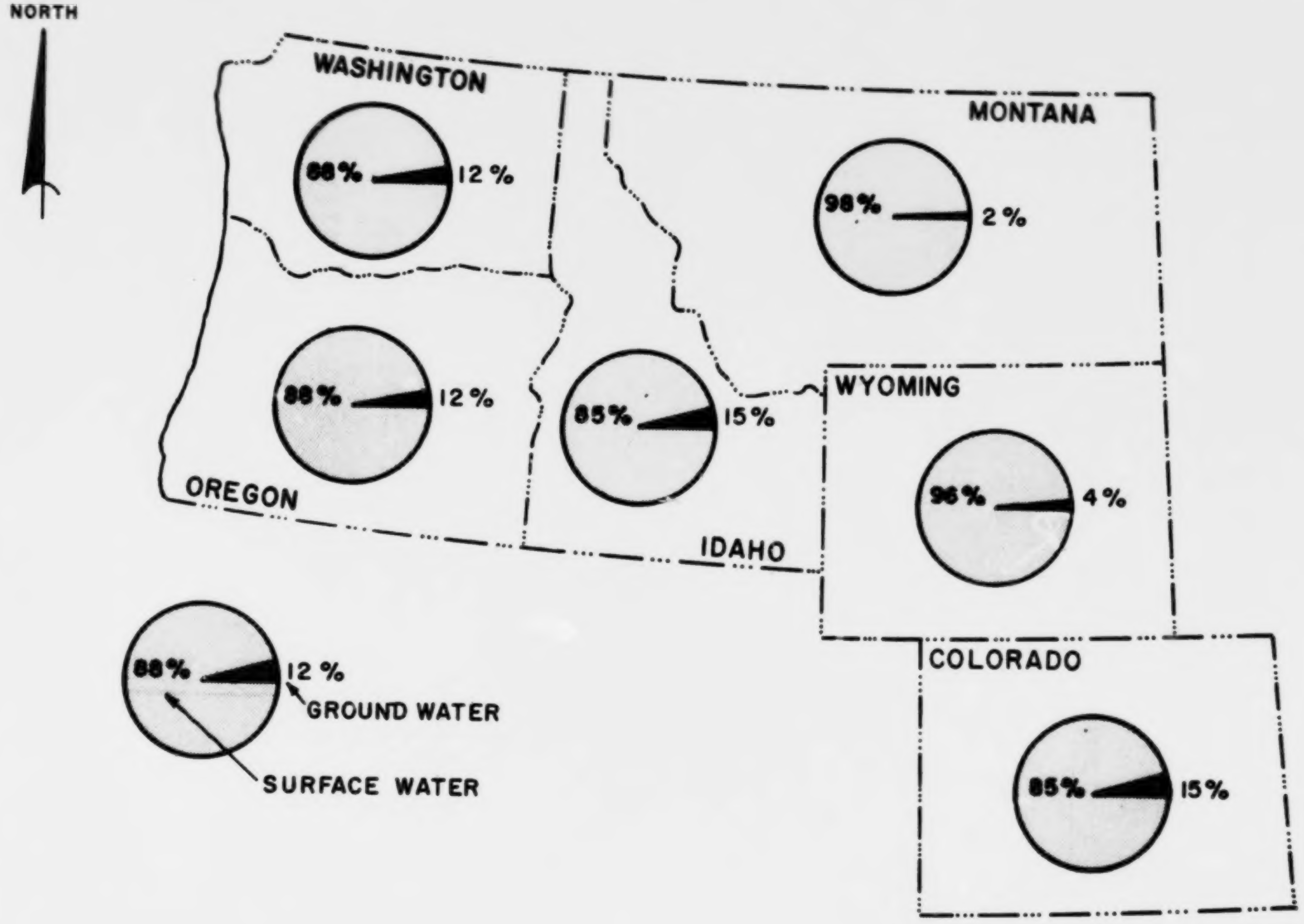
NORTH
WASHINGTON
88%
12 %
MONTANA
98%
2 %
OREGON
88%
12 %
85%
15%
IDAHO
WYOMING
96%
4 %
COLORADO
85%
15%
88%
12 %
GROUND WATER
SURFACE WATER

Figure 1. Comparison of ground-water use to surface-water use in 1970. 1)

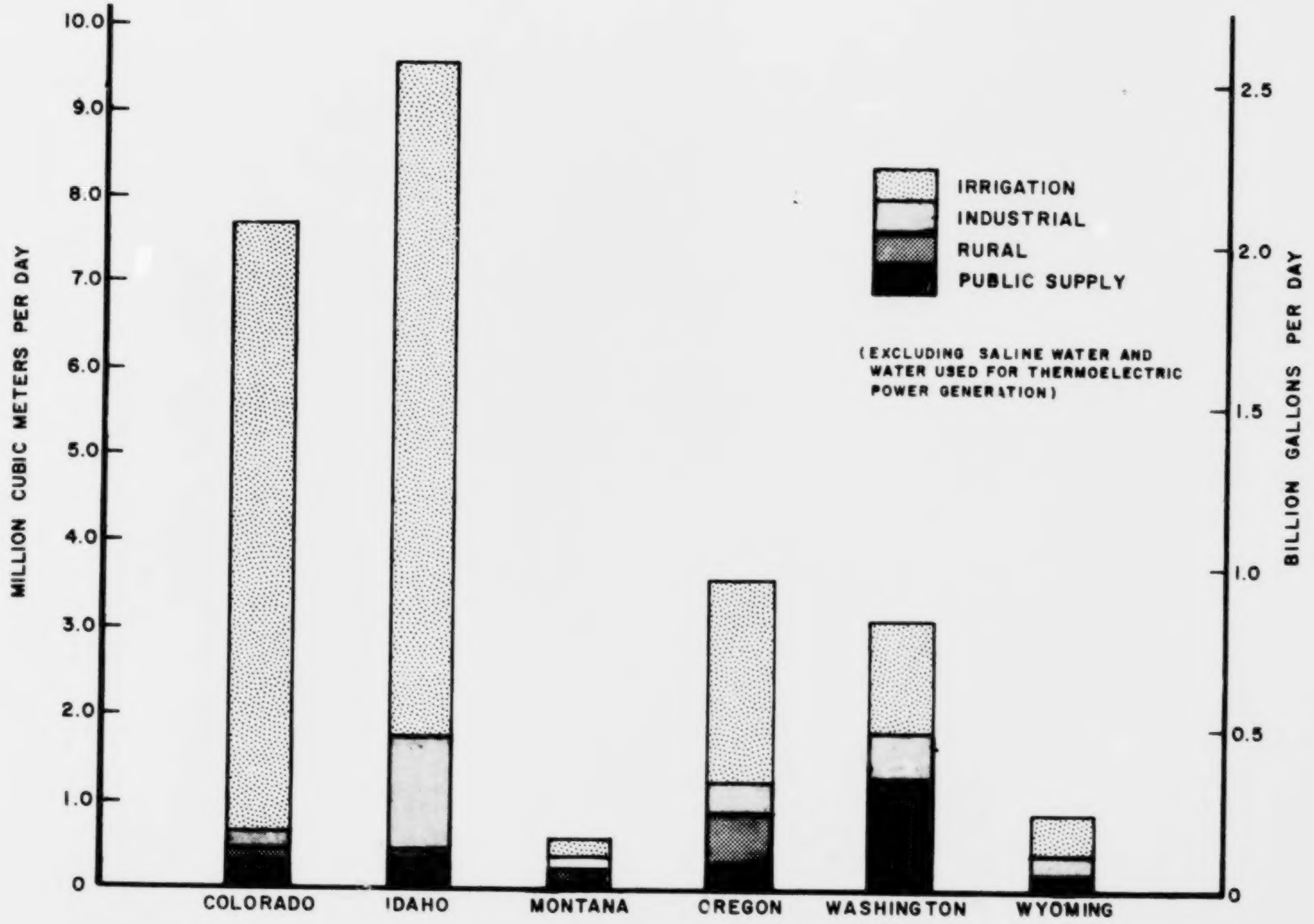

Figure 2. Use of ground water in 1970. 1)

from wells.

Irrigation water use is large and represents 89 percent of all water withdrawn in the project area. Ten percent of the water used for irrigation supplies is derived from wells. The states with the largest ground-water withdrawal for irrigation are Idaho (9.7 cu hm/d or 2.6 bgd) and Colorado (7.8 cu hm/d or 2.1 bgd).

TRENDS IN GROUND-WATER USE

Projections of water use in the United States indicate that sharp increases may be expected in municipal, self-supplied industrial and agricultural water use in the next 30 years. By the year 2000, self-supplied industrial water demand will triple, municipal water use will double, and the agricultural demand will increase some 50 percent. 4) Projected fresh water withdrawals for the steam-electric power industry will increase by about 400 percent in the same period.

New mining development of oil shale and coal in Montana, Wyoming and Colorado will require large quantities of water for cooling and processing. In the Great Plains, surface-water rights claim most runoff and no or very few additional surface-water diversions are possible. For these reasons, it is expected that ground water will play an increasingly important role in water development.

A comparison of water-use data for the years 1965 and 1970 shows some interesting trends in ground-water use (see Table 2). 1,11) Total ground-water use for the study area increased 9 percent in the five-year period, or roughly 2 percent per year. On a state basis, however, except for Idaho, the increase was considerably more and ranged from 15 percent in Washington to 136 percent in Wyoming.

By category the following trends appear:

Public Supply - There is a general increase in ground-water use in all states, most pronounced in Colorado (40 percent) and Washington (16 percent).

Rural Supply - Generally a slight increase except in Oregon where rural ground-water use jumped from 136,000 to 606,000 cu m/d (36 to 160 mgd). This appears to be indicative of a rapid growth of self-supplied homes outside the urban areas.

Industrial Supply - Generally on an upward trend except in Oregon where ground-water use decreased from 606,000 to 416,000 cu m/d (160 to 110 mgd). A large change took place

Table 2. GROUND-WATER USE, 1965-70.[1,11)

(in mgd)

State	1965		1970		Percent of increase (+) or decrease (-) over 1965
	1,000 m^3/d	mgd	1,000 m^3/d	mgd	
Colorado	6,185	1,634	7,809	2,063	+ 26
Idaho	11,408	3,014	9,720	2,568	- 15
Montana	307	81	564	149	+ 84
Oregon	2,680	708	3,661	967	+ 37
Washington	2,767	731	3,173	838	+ 15
Wyoming	371	98	875	231	+136

in Idaho where ground-water use increased from 344,000 to 1,287,000 cu m/d (91 to 340 mgd). This is believed to be due to increased industrial development in the food processing sector.

Irrigation - This category showed the most change with considerable increases (20 to 40 percent) in ground-water use (except for Idaho). The increase in Colorado was 26 percent; Oregon, 40 percent; and Washington, 21 percent. Irrigation with ground water in Montana increased from zero in 1965 to 238,000 cu m/d (63 mgd) in 1970. In Wyoming, irrigation with ground water multiplied several times from 102,000 to 492,000 cu m/d (27 to 130 mgd). Use of ground water in Idaho, however, dropped 25 percent from 10.6 to 7.8 cu hm/d (2.8 to 2.1 bgd). It is believed that this reduced withdrawal represents, at least in part, a change-over from ditch irrigation to overhead spray irrigation, which uses less water.

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SECTION IV

DESCRIPTION OF PROJECT AREA

The project area encompasses the six states of Colorado, Wyoming, Montana, Idaho, Oregon, and Washington, an area of roughly 1.5 million sq km or 600,000 sq mi, representing 20 percent of the total land surface of the conterminous United States. The project area is characterized by a wide variety of land-form features. Large physical divisions are the Great Plains, the Rocky Mountains, Intermontane Plateaus, the Pacific Mountain System, and numerous large basins and lowland regions. Elevations of the land surface range from sea level along the Pacific coast to over 3,000 m or over 10,000 ft in the Rocky Mountain region.

PHYSIOGRAPHY

In 1951, H. E. Thomas divided the United States into 10 distinct ground-water regions. 1) Within the boundaries of the project area, the following seven regions are present:

1. Western Mountain Ranges
2. Alluvial Basins
3. Columbia Plateau
4. Colorado Plateau and Wyoming Basin
5. High Plains
6. Unglaciated Central Region
7. Glaciated Central Region

These seven ground-water regions together with principal aquifers and centers of major ground-water withdrawal are shown in Figure 3. Almost half of the project area lies within the Western Mountain Ranges. Also encompassing large areas are the Columbia Plateau and the Unglaciated Central Region. Of relatively small extent are the Alluvial Basins and the High Plains Region.

The Western Mountain Ranges include the Coast and Cascade Ranges in Oregon and Washington, the Olympic Mountains in Washington, the Bitterroot Range, Clearwater and Salmon River Mountains in Idaho, and the Rocky Mountains in Montana, Wyoming and Colorado. It is in this region, which includes some of the most spectacular mountains of the nation, that the principal source of water in the project area originates. The bulk of the precipitation falls on these mountains and gives rise to great rivers, among which are the Snake, Columbia, Missouri, Platte, Arkansas, Rio Grande, and Colorado. The mountains generally consist of hard or crystalline rock

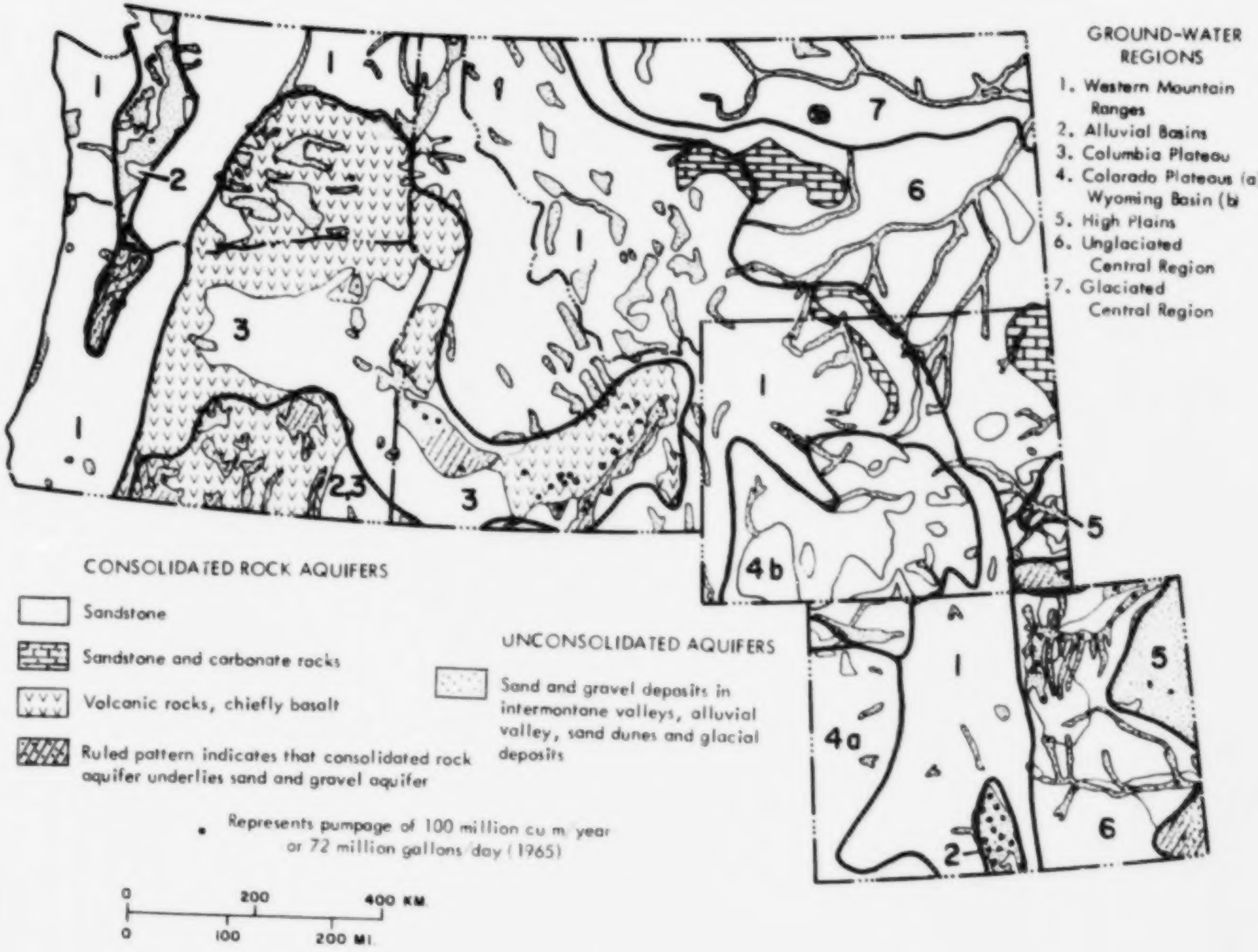

GROUND-WATER REGIONS
1. Western Mountain Ranges
2. Alluvial Basins
3. Columbia Plateau
4. Colorado Plateaus (a) Wyoming Basin (b)
5. High Plains
6. Unglaciated Central Region
7. Glaciated Central Region
CONSOLIDATED ROCK AQUIFERS
Sandstone
Sandstone and carbonate rocks
Volcanic rocks, chiefly basalt
Ruled pattern indicates that consolidated rock aquifer underlies sand and gravel aquifer
UNCONSOLIDATED AQUIFERS
Sand and gravel deposits in intermontane valleys, alluvial valley, sand dunes and glacial deposits
Represents pumpage of 100 million cu m/year or 72 million gallons/day (1965)
0
200
400 KM
0
100
200 MI
1
2
3
2,3
4a
4b
5
6
7

Figure 3. Ground-water regions and major aquifers. 1,2)

and form poor aquifers. However, alluvial deposits and glacial outwash in valley areas can constitute prolific aquifers. An example of the latter are the glacial outwash deposits in the Spokane Valley-Rathdrum Prairie area in Washington and Idaho.

The Alluvial Basins are structural depressions that were filled with unconsolidated material in Pleistocene and Recent times. They form the natural collection areas for streamflow from the surrounding uplands. The region includes the Willamette River basin in Oregon, the Puget Sound Lowland in Washington, and the San Luis Valley in Colorado. The Puget-Willamette Trough lies between the Coast Range and the Cascade Range. This lowland is intensively developed and urbanized in the Portland and Seattle-Tacoma region. The San Luis Valley is an important irrigated agricultural area and the site of the largest ground-water withdrawal in Colorado.

The Columbia Plateau ground-water region is bounded on the west and north by the Cascade Range and to the east by the Rocky Mountains. It covers eastern Washington, eastern Oregon, and southern Idaho. The Plateau consists of lava rocks, hundreds of meters thick in places, with permeable zones that constitute enormous and highly productive aquifers. The lava plateau receives excellent recharge from infiltrating streams. The plateau is deeply dissected by streams and depth to ground water is great in some areas. The aquifer is widely tapped for irrigation in the Snake River Plain of Idaho.

The Colorado Plateau and the Wyoming Basin are regions underlain by sedimentary rocks, chiefly interbedded sandstone and shale. The plateaus are deeply dissected by the Colorado River and the Missouri River and their tributaries. Compared with the Columbia Plateau, the rocks have low permeability and receive fairly little precipitation. Both plateaus are water-poor areas with low runoff and relatively poor aquifers. Alluvium is present in the principal stream valleys, and important alluvial basins are found along the Yampa and Green Rivers in northwestern Colorado and the Sweetwater River in Wyoming. Extensive oil-shale deposits also are present within the region.

The High Plains ground-water region of eastern Colorado and eastern Wyoming constitutes the northwestern edge of an immense alluvial deposit laid down on sedimentary rocks in Tertiary time. This alluvium, which in places is over 160 m (500 ft) thick, extends into Kansas and Nebraska and southward into Oklahoma and Texas. It is known as the Ogallala Formation. Precipitation is low and natural replenishment to the Ogallala aquifer is very small. In recent years, the northern part of the Colorado High Plains has undergone a change from dry land to irrigated agriculture using water from the Ogallala Formation.

The Unglaciated Central Region in Montana, Wyoming and Colorado is part of the vast interior region of the United States. It is characterized by plains and plateaus underlain by horizontal or gently eastward-dipping sedimentary rocks. Aquifers in most of the region are sandstones, generally of relatively low yield. Some productive limestones (e.g. the Madison) are present in Montana and Wyoming. Saline ground water is generally present at shallow depths over most of the region and saline springs are common in Montana. Included within the region is the Denver Basin in Colorado, an area of intensive ground-water development.

The Glaciated Central Region covers a strip some 160 km (100 mi) wide along the Canadian border in Montana. The region is quite similar to the Unglaciated Central Region in physiography and rock types. However, a mantle of glacial drift overlies the bedrock. This drift consists mostly of fine-grained rock debris (till) and contains almost no beds of permeable material. Principal aquifers are found along water courses where the rivers have washed away fine-grained material from the glacial deposits, leaving behind permeable sands and gravels. Recharge to the underlying bedrock aquifers is small, due to low precipitation and the drift cover.

General geologic conditions in the project area are shown on Figure 4. The map shows the type of bedrock and distinguishes between crystalline rock (igneous and metamorphic rocks), volcanic rocks, and sedimentary rocks. Major areas of unconsolidated material in river valleys, plains and intermontane valleys are also shown. Volcanic and crystalline rocks cover well over 50 percent of the project area.

Investigations of ground-water conditions have been carried out through cooperative programs between state agencies and the U. S. Geological Survey and by state universities. General ground-water information is available for about 50 percent of the project area, but almost no information is available for the little-populated mountain zones. Detailed ground-water studies have been carried out in only a few urban areas.

POPULATION

Of the nation's 203.2 million people, some 9.5 million or 4.7 percent resided in the project area according to the

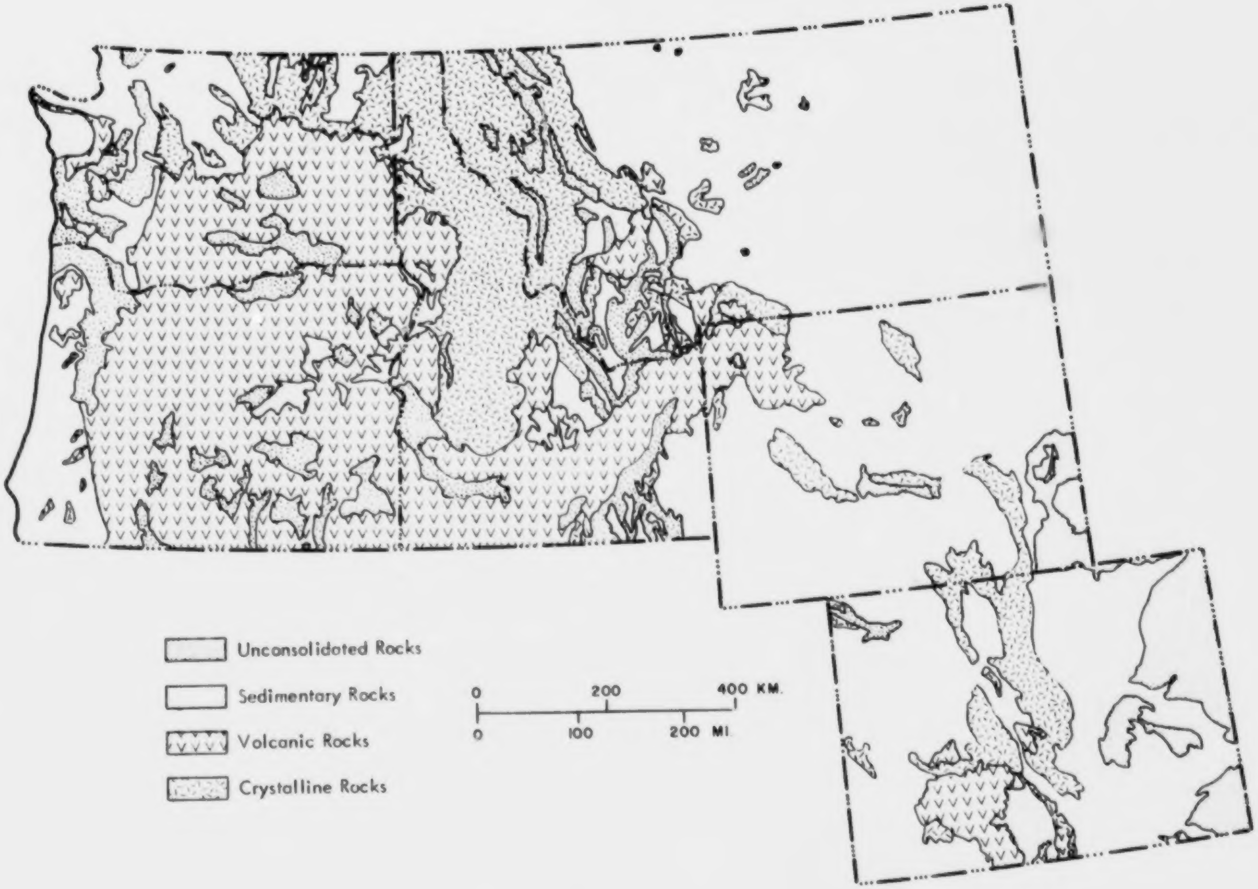

Unconsolidated Rocks
Sedimentary Rocks
Volcanic Rocks
Crystalline Rocks
0
200
400 KM.
0
100
200 MI.

Figure 4. Geology of the northwestern states. 3)

1970 Census. 4) Characteristics of the population in each state are shown on Table 3. Colorado, Oregon and Washington have the highest population and show a relatively large increase in population in the 1960-70 period (18 to 25 percent). In these states, most of the population is concentrated in urban centers. By contrast, Wyoming, Montana and Idaho have a small population which is mostly rural and has shown little increase over the years. The largest cities in the project area are Denver (pop. 512,691), Seattle (pop. 524,263), and Portland (pop. 375,161). Important regional concentrations of population are the Seattle-Tacoma urban area (pop. 2,000,000), and the Greater Denver metropolitan area (pop. 1,200,000). Population growth in the metropolitan areas is expected to continue in the next 20 years. The population of the Denver area, which contains more than 75 percent of the total population of Colorado, is projected to be over 2,000,000 by 1990. 5)

CLIMATE

Climatic conditions vary widely in the project area because of the varied topography and movement of air masses across the continent. The Pacific zone has a coastal-marine climate, with high precipitation (Figure 5), high runoff (Figure 6) and low evaporation rates. Eastward the climate becomes the high-desert type with low precipitation, low runoff and high evaporation rates. Locally, mountain ranges cause wide variations in climatic conditions.

About 60 percent of the project area is water-deficient (Figure 6). The Pacific coastal zone, especially the western slopes of the Coast Range and Cascade Range, is one of the areas of highest precipitation in the United States (2,000 to 3,500 mm or 80 to 140 in per year). A sharp drop in precipitation takes place east of the Cascade Range. Precipitation is generally less than 500 mm (20 in) per year over Idaho, Montana, Wyoming and Colorado. Snowfall is heavy in the Rocky Mountains, the Cascade Range and in northeastern Oregon, and locally reaches 2,500 to 5,000 mm (100 to 200 in) per year. Snow melt in spring provides heavy runoff that, when stored in reservoirs, becomes available for water supply.

GEOLOGY AND GROUND-WATER RESOURCES

Following is a discussion of the general geology in relation to the ground-water resources on a state-by-state basis. For each state, surface-water resources are briefly discussed followed by a review of ground-water use. Hydrogeologic conditions in each of the major river basins and water-

Table 3. POPULATION CHARACTERISTICS. 4)

State	1970 Population	Percent increase 1960 to 1970	Places over 25,000 population	Places over 100,000 population	Population distribution (percent)	
					Urban	Rural
Colorado	2,207,259	25.8	10	2	75	25
Idaho	713,008	6.9	4	None	48	52
Montana	694,409	2.9	3	None	51	49
Oregon	2,091,385	18.2	5	1	65	35
Washington	3,409,169	19.5	11	3	69	31
Wyoming	332,416	0.7	2	1	58	42
TOTAL:	9,447,646	12.3	35	7		

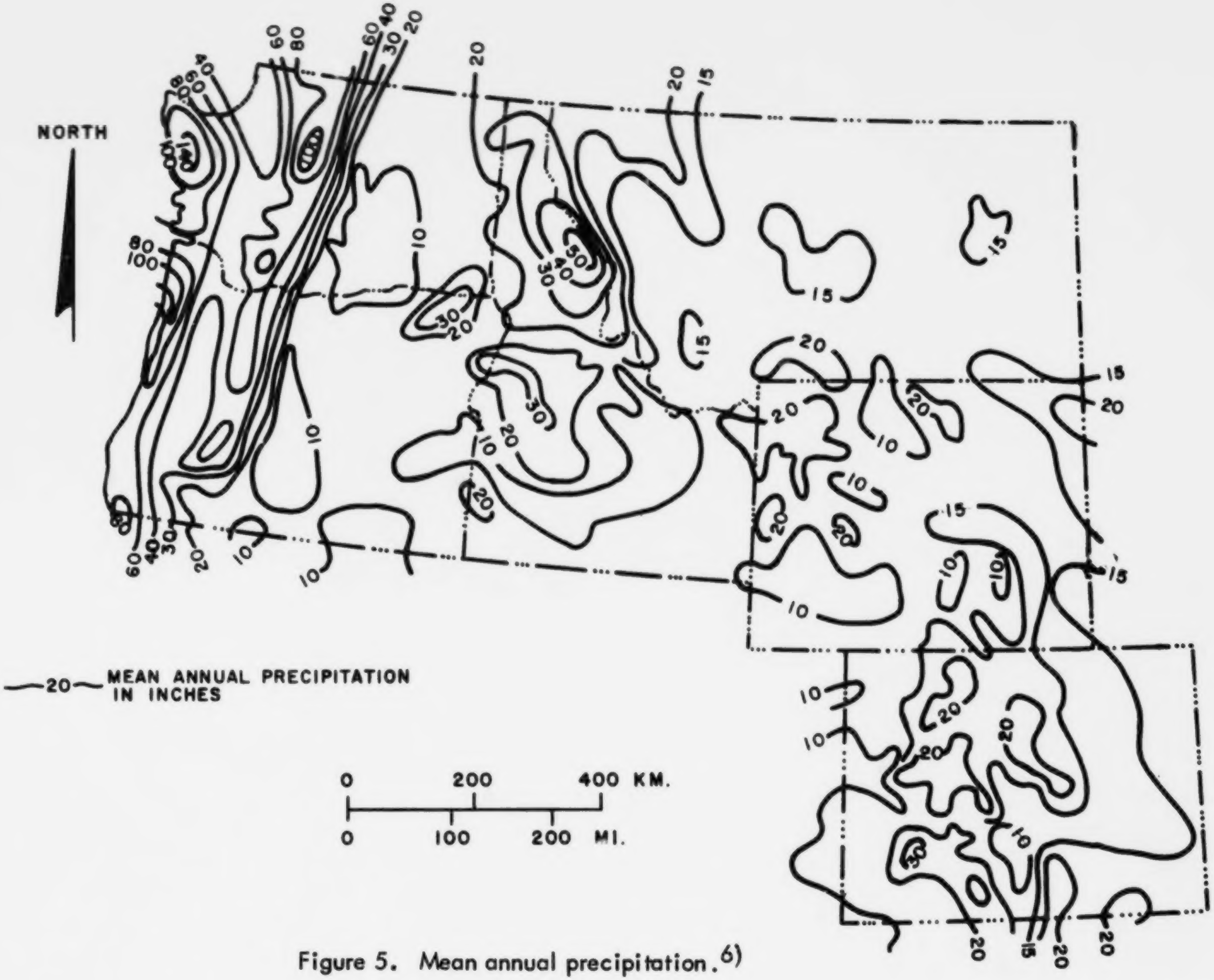

NORTH
—20— MEAN ANNUAL PRECIPITATION IN INCHES
0 200 400 KM.
0 100 200 MI.
140
100
80
60
40
30
20
10
15
50

Figure 5. Mean annual precipitation.6)

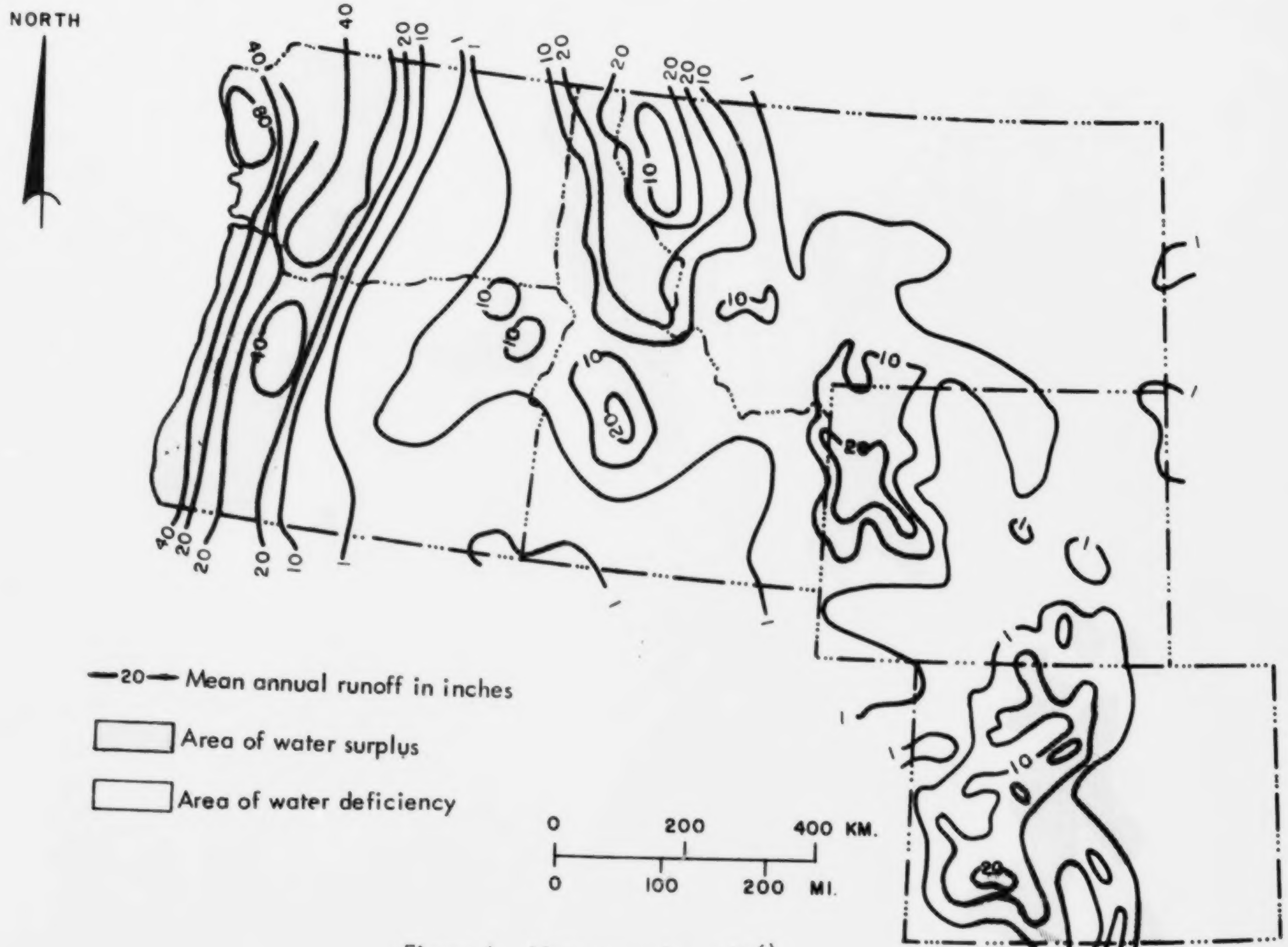

NORTH
20 Mean annual runoff in inches
Area of water surplus
Area of water deficiency
0
200
400 KM.
0
100
200 MI.
80
40
20
10
1

Figure 6. Mean annual runoff.6)

bearing characteristics of principal aquifers are described.

Colorado

Colorado is an area of mountains and high plateaus and plains lying across the highest part of the Continental Divide. Precipitation is 500 to 750 mm (20 to 30 in) in the mountainous area but drops to 300 to 400 mm (12 to 16 in) in the eastern and western portions of the state and to 150 mm (6 in) in the San Luis Valley. The Rocky Mountain area forms the headwaters for such major western rivers as the Platte, Arkansas, Rio Grande, and Colorado. Available flow in the major rivers is some 53 cu hm/d, equivalent to 14 bgd or 16 million acre-ft; however, under existing compacts and decrees, about half of this water must be delivered to downstream states. Water of the South Platte, Arkansas, and Rio Grande Rivers, about one-quarter of the total supply, is already fully appropriated, while that of the Colorado River, about two-thirds of the total for the state, is expected to be fully utilized within 50 years. Only about one-third of the river flow of 37 cu hm/d (11 million acre-ft per year) can be used within Colorado.

Concentration of the population in the water-short Lower Platte River basin has created problems of water distribution and has necessitated diversion of Colorado River water eastward to the Denver metropolitan area. Continued growth of population and industrial development in the South Platte and Arkansas basins will be limited, unless additional water can be made available through importation, salvage and reuse. 7)

The state's ground-water resources are largely east of the Continental Divide. Major ground-water areas are shown on Figure 7; principal aquifers and well yields are depicted on Figure 8. The principal aquifers are the alluvial sand and gravel deposits in the Platte and Arkansas River valleys and in the San Luis Valley of the Rio Grande, and the Ogallala Formation of the High Plains. Sandstones yielding moderate supplies of ground water are important aquifers in the Denver Basin and south of the Arkansas River between Pueblo and the Kansas state line in the so-called Arkansas Valley Artesian Area. West of the Divide the principal aquifers are the alluvial deposits along the Yampa and Green Rivers, and the sandstones of the Colorado Plateau and the Wyoming Basin.

Ground-water use in the state is growing rapidly and the total withdrawal amounts to over 7.5 cu hm/d (2.0 bgd). Most of this water (95 percent) is used for irrigation in

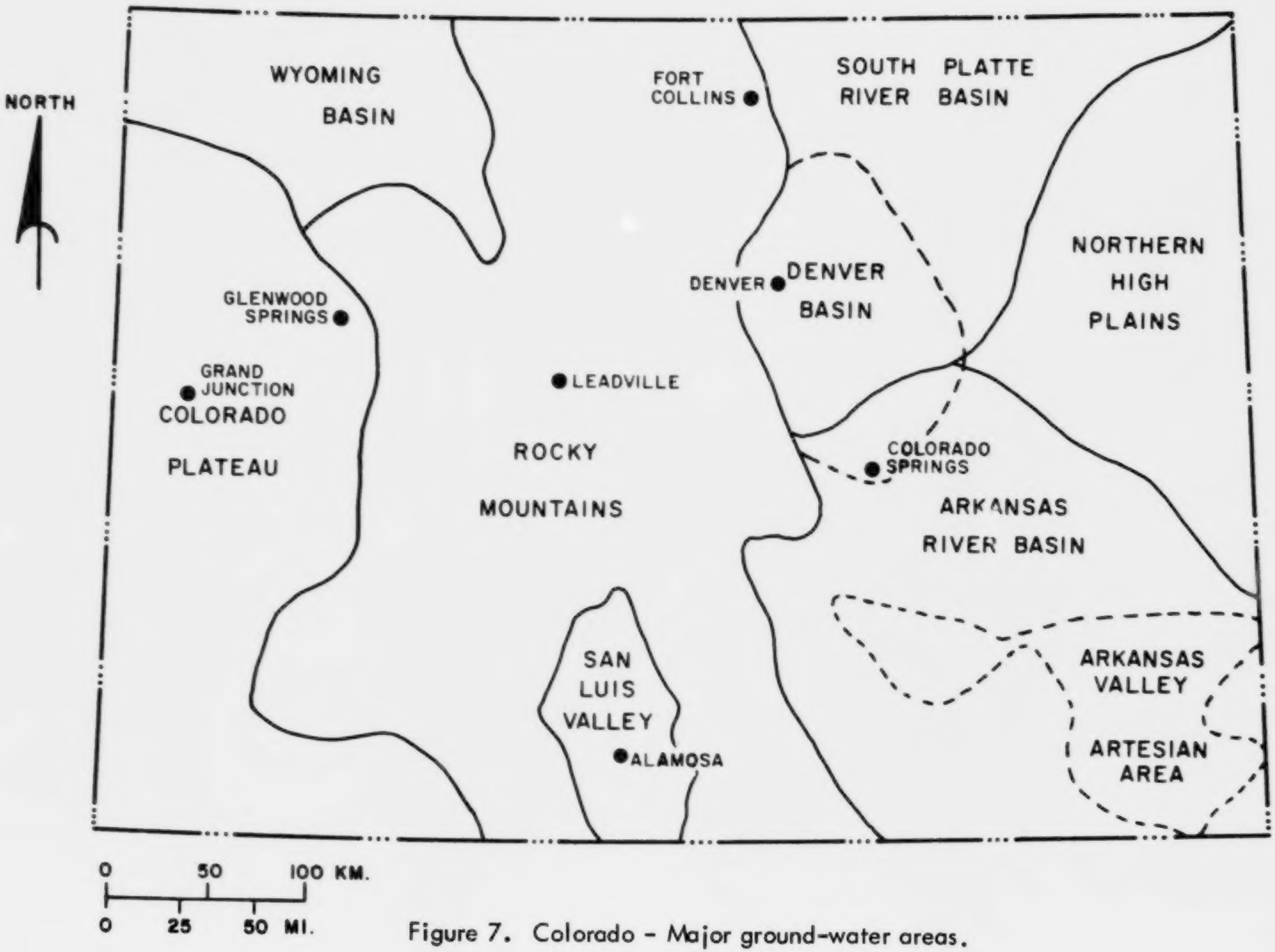

NORTH
WYOMING BASIN
FORT COLLINS
SOUTH PLATTE RIVER BASIN
GLENWOOD SPRINGS
DENVER
DENVER BASIN
NORTHERN HIGH PLAINS
GRAND JUNCTION
LEADVILLE
COLORADO PLATEAU
ROCKY MOUNTAINS
COLORADO SPRINGS
ARKANSAS RIVER BASIN
SAN LUIS VALLEY
ALAMOSA
ARKANSAS VALLEY
ARTESIAN AREA
0
50
100 KM.
0
25
50 MI.

Figure 7. Colorado - Major ground-water areas.

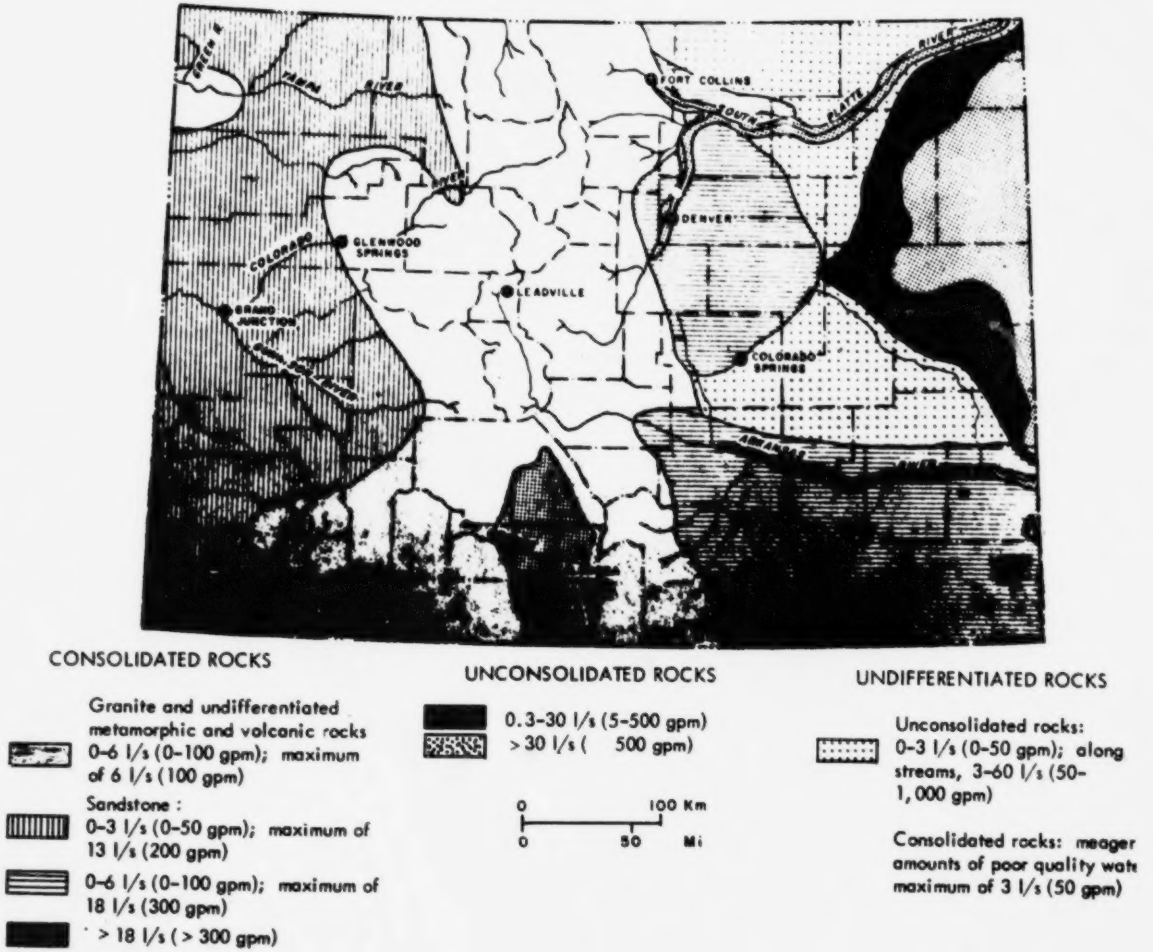

FORT COLLINS
SOUTH PLATTE RIVER
DENVER
GLENWOOD SPRINGS
COLORADO
RIVER
YAMPA RIVER
LEADVILLE
GRAND JUNCTION
COLORADO SPRINGS
ARKANSAS RIVER
CONSOLIDATED ROCKS
Granite and undifferentiated metamorphic and volcanic rocks
0–6 l/s (0–100 gpm); maximum of 6 l/s (100 gpm)
Sandstone :
0–3 l/s (0–50 gpm); maximum of 13 l/s (200 gpm)
0–6 l/s (0–100 gpm); maximum of 18 l/s (300 gpm)
> 18 l/s (> 300 gpm)
UNCONSOLIDATED ROCKS
0.3–30 l/s (5–500 gpm)
> 30 l/s (500 gpm)
0 100 Km
0 50 Mi
UNDIFFERENTIATED ROCKS
Unconsolidated rocks: 0–3 l/s (0–50 gpm); along streams, 3–60 l/s (50–1,000 gpm)
Consolidated rocks: meager amounts of poor quality wat
maximum of 3 l/s (50 gpm)

Figure 8. Colorado – Major aquifers and well yields.[8)]

the South Platte and Arkansas River basins and in the San Luis Valley. In recent years a rapid increase in irrigation has taken place in the High Plains of eastern Colorado using water from the Ogallala aquifer.

Surface water and ground water in the alluvial aquifers are closely interrelated. Alluvial aquifers are recharged by river water, and in turn, ground-water recharge, for example from irrigation return flows, contributes heavily to the flow of some rivers.

Ground-water studies have been made by the U. S. Geological Survey, the Colorado Water Conservation Board (in cooperation with the U. S. Geological Survey) and the Colorado State Department of Public Health. In recent years, some investigations on ground water and ground-water quality have been carried out by Colorado State University.

South Platte River Basin -

The South Platte River basin is the most intensively developed irrigated area in Colorado. The water-bearing characteristics of the valley-fill aquifers are excellent for development of large, low-cost water supplies from shallow wells for irrigation, municipal and industrial use. Wells yield up to 190 l/s or 3,000 gpm, and yields of 30 l/s (500 gpm) are common.

The valley-fill deposits reach their maximum thickness in the main South Platte River valley and in the lower reaches of most of its tributaries. The saturated thickness of the aquifer ranges from 12 to 40 m (40 to 120 ft) in the main valley between the southern Weld County line and the town of Kuner, is over 25 m (80 ft) in an area downstream of the town of Orchard to the state line, and is 48 to 72 m (160 to 240 ft) in the lower basin. Depth to the water table in the main valley is generally less than 3 m (10 ft) in the lowlands and increases to about 15 m (50 ft) in the upland areas. In the tributary river valleys, such as the lower Cache la Poudre River and Boxelder Creek, the valley-fill material generally ranges from 12 to 30 m (40 to 100 ft) in thickness. Over 30 m (100 ft) are reported in the valleys of Lost Creek, Bijou, Kiowa, Badger, and Beaver Creeks. Dune sand deposits, which reach a thickness of 30 m (100 ft) in places, cover an area of over 2,600 sq km (1,000 sq mi) in Weld, Morgan, Logan, and Washington Counties. These deposits yield small quantities of water to wells but are important for infiltration of precipitation and runoff, and thus, for recharge of underlying aquifers. 9)

Bedrock aquifers are the crystalline Precambrian age rocks exposed in the Front Range that yield small supplies (0.3 to 0.6 l/s equivalent to 5 to 10 gpm) to individual wells and sedimentary rocks of Cretaceous age capable of yielding moderate supplies to wells (0.6 to 5 l/s or 10 to 75 gpm). The sedimentary rock aquifers are discussed separately in the section describing the Denver Basin.

There are over 10,000 water wells in the South Platte River basin, most of which tap the alluvial aquifer (Table 4). Over 6,000 of these are large-capacity irrigation wells.

The volume of ground water moving through the alluvial aquifer is large. The U. S. Geological Survey has estimated the underflow in the alluvium of the main valley at 390 l/s (10,000 acre-ft per year) north of Denver, 510 l/s (13,000 acre-ft per year) at Greeley, 470 l/s (12,000 acre-ft per year) at Kersey and 310 l/s (8,000 acre-ft per year) at the state line. Ground-water withdrawals have increased considerably in the last few years. An estimated 1.5 billion cu m (1.2 billion acre-ft) was pumped for irrigation in 1967 compared with 900 million cu m (730,000 acre-ft) in 1959. Municipal and industrial pumpage in recent years is estimated at roughly 123 million cu m (100,000 acre-ft), and the total withdrawal of ground water is some 1.6 billion cu m (1.3 million acre-ft).

Over the years, seepage from surface reservoirs, canals and surplus irrigation water has caused the water table to rise above the river bed. The result was that the South Platte River became a gaining stream carrying water on a year-round basis. Downstream, irrigators filed for rights to use this water and have become entirely dependent upon this "return flow". 11) Recent studies of gaging records show that the river gains some 70 l/s per km (2,900 acre-ft per mi) per year between Denver and Julesburg. 9) The highest gains of 89 to 110 l/s per km (3,700 to 4,500 acre-ft per mi) per year take place in the Fort Lupton-Fort Morgan stretch and in densely irrigated areas.

Infiltration from seepage losses of irrigation conveyance systems and percolation on irrigated farms is estimated at 50 percent of the South Platte River water diverted. Thus, annually some 740 million cu m (600,000 acre-ft) enters the unconfined aquifers in the agricultural area of the main valley and its southern tributary valleys. In comparison, infiltration into the valley-fill deposits from precipitation is small and estimated at about one inch per year.

Monitoring of ground-water levels in the main valleys has

Table 4. COLORADO. USE OF WATER WELLS IN SOUTH PLATTE RIVER BASIN. 9,10)

Type	Denver to Brighton	Brighton to State Line	South Platte River Basin Total
Irrigation wells	397	5,063*	6,240
Municipal water systems	38	96	134
Domestic, motels, restaurant, other	546	3,497	4,046
Industrial and commercial	85	211	199
Stock	10	780	10
TOTALS:	1,076	9,647	10,629

* Valley-fill aquifer only.

shown no long-term decline indicating that the recharge balances withdrawals. 10) However, in some heavily pumped tributary valleys, such as Prospect Valley and the areas of Kiowa, Bijou, and Beaver Creek, long-term water levels are declining at the rate of about one ft per year. 7)

Arkansas River Basin -

The Arkansas River valley is the third most productive irrigated area in Colorado with hydrologic conditions quite similar to those of the South Platte River basin. The main river valley and tributary valleys are intensively irrigated. Water is obtained from the Arkansas River and from ground water present in the alluvium, which is an excellent aquifer with high transmissivities. The aquifer occupies a trough eroded into shale, limestone and sandstone bedrock of Cretaceous age. This bedrock is relatively impermeable and acts as a barrier to ground-water movement. In Bend County (Las Animas region), the saturated thickness of the valley fill varies from 3 to 20 m (10 to 60 ft), and the transmissivity in the main valley varies from 1,200 to 3,700 sq m/d (100,000 to 300,000 gpd/ft).

The saturated valley-fill deposits range in thickness from 0 to 75 m (250 ft) and contain an estimated 2.5 billion cu m (2 million acre-ft) of water in storage. 12) The aquifer is in hydraulic connection with the Arkansas River. Irrigation water is diverted from the Arkansas River and also pumped from wells. Surface-water diversions averaged 940 million cu m (760,000 acre-ft) per year and ground-water withdrawals 173 million cu m (140,000 acre-ft) per year during the period 1958-1968.

The major part of the irrigation return flow discharges to the Arkansas River as revealed by river gaging records. For example, along an 8 to 13 km (5 to 8 mi) stretch of the river downstream of Las Animas, the river gained 1,330 l/s or 47 cfs on October 31, 1967. 12) Since the start of surface-water irrigation in 1859, some 24 canals have been constructed to divert water from the Arkansas River for application on the land between Pueblo and the Kansas state line. Streamflow is derived from precipitation - chiefly snowmelt in the Rocky Mountains. In late summer, the surface-water supply is commonly inadequate to meet irrigators' needs.

Wells drilled mostly between 1950 and 1965 are needed to provide irrigation water when surface supplies are deficient. In 1969 there were some 1,350 irrigation wells tapping the valley-fill aquifer in the Arkansas River valley. 12) Ground-water withdrawal for irrigation averaging 102 million cu m (83,000 acre-ft) per year from 1950 to 1959, increased to 173 million cu m (140,000 acre-ft) per year in the 1960 to 1969 period. The yield of irrigation wells varies from 6 to 160 l/s (100 to 2,500 gpm).

Aside from the valley-fill aquifer, small to moderate supplies of ground water can be obtained from Cretaceous sandstones (Cheyenne Sandstone of the Purgatoire Formation and Dakota Sandstone). These formations are present below the entire Arkansas River basin but are only within reasonable drilling depth in the area south of the Arkansas River from Carson City to the Kansas state line. This region is called the Arkansas Valley Artesian Area. The sandstones yield small to moderate supplies of 0.6 to one l/s (10 to 15 gpm) to wells, with exceptionally higher yields (greater than 20 l/s or 300 gpm) in areas where the formation is coarse-grained (Baca and Prowers Counties). The sandstones are primarily tapped by domestic and municipal wells, but in high-yield areas the aquifers are pumped for irrigation. The present withdrawal is not known, but in 1959 municipal wells pumped some 3 million cu m (2,400 acre-ft). 7)

Denver Basin -

The Denver Basin surrounds the city of Denver, extending on the west to the mountains and some 130 to 200 km (50 to 75 mi) north, east and south of the city. Ground water is obtained from alluvial deposits in the South Platte River valley and its tributaries and from a sequence of sedimentary rock aquifers, some of which are unconsolidated in nature. 13)

The alluvial deposits reach a maximum thickness of 20 m (60 ft) and yield large quantities of water where sufficiently saturated. Municipal water wells producing from the alluvium in the Cherry Creek valley, for example, yield from 55 to 115 l/s (900 to 1,800 gpm). 14) The principal bedrock aquifers are the Dawson and Laramie Formations and the Fox Hills Sandstone. Older Mesozoic and Paleozoic formations are capable of yielding small to moderate quantities of water to wells, but because of their great depth, these aquifers are not developed.

The upper part of the Dawson Formation (thickness 100 to 335 m or 300 to 1,100 ft) is composed of shale, clay, siltstone, sandstone and beds of arkosic conglomerate, sand and gravel, and some beds of lava and tuff. The conglomerate zone ("upper conglomerate") and lenticular gravel beds that lie from 60 to 120 m (200 to 400 ft) above the conglomerate zone yield moderate amounts of water. The lower part of the Dawson Formation (thickness 120 to 460 m or 400 to 1,400 ft) consists of arkosic sand, gravel, and conglomerate interbedded with shale and clay. The thickest and most extensive zones of coarse sediments in the upper 230 m (700 ft) are known as the "middle" and the "lower conglomerate". Each of these zones ranges in thickness from 16 to 60 m (50 to 200 ft) and yields moderate quantities of water.

Below the Dawson Formation is the Laramie Formation which is composed of sandstone, limestone, lignite and coal beds. Two sandstone beds in the formation, known as the "A" sandstone and "B" sandstone, each 10 to 30 m (30 to 100 ft) thick, yield small to moderate supplies of water to wells. The Milliken Sandstone member of the Fox Hills Sandstone found below the Laramie Formation constitutes the lowest principal aquifer in the basin. This sandstone yields small to moderate quantities of water.

Long-term pumpage from the Dawson and Fox Hills aquifers in the Denver area has created local cones of depression of 100 to 200 m (300 to 600 ft), and pumping lifts are now considerable. 7) Artificial recharge of the aquifers through wells appears to be feasible.

High Plains -

The High Plains ground-water reservoir in eastern Colorado lies within the Kansas River basin and extends into the Arkansas River basin. The principal aquifer is the Ogallala Formation which extends beyond the state line and underlies large areas in Texas, Oklahoma, Kansas and Nebraska. The formation consists of clay, silt, sand, and gravel and varies considerably in thickness and permeability from place to place. The sediments were deposited on an irregular, sloping bedrock surface and the formation thickens eastward to about 120 m (400 ft) at the Kansas state line. Dune sand overlies about 4,000 sq km (1,600 sq mi) of the Ogallala in the northern High Plains. Upper Cretaceous shales and siltstones underlie the Ogallala below the northern High Plains and form an almost impermeable barrier. Further south the aquifer is underlain by shales and sandstones.

The Ogallala is widely tapped by municipal, domestic and irrigation wells. In recent years, a significant rise in the rate of new irrigation wells drilled has caused concern for proper management of the resource in view of a low recharge rate to the aquifer. 7)

In the southern Plains region, the Dakota and Cheyenne Sandstones are present below the Ogallala. These sandstone aquifers are also quite irregular in thickness, depth and extent, and are typically separated from the Ogallala by shale beds of the Pierre Formation. Where confined, the Dakota and Cheyenne are artesian, and can supply moderate quantities of water; however, the aquifers are little developed. Other aquifers are permeable sandstones within the White River Group of Oligocene age and alluvial deposits in river channels.

Water levels in the Ogallala aquifer are low as a result of the incised river drainage, and only about the lower one-third of the formation is saturated. The thickness of saturated material in the formation ranges from a few feet along the western edge of the High Plains to about 115 m (350 ft) in the eastern part. Low water levels cause pumping lifts to be on the order of over 50 m (several hundred ft). The necessity for deep wells and the high electric power costs cause this irrigation water to be the most expensive in the state.

The amount of water stored within the Ogallala is tremendous. The aquifer covers an area of approximately 30,000 sq km (12,000 sq mi) in Colorado, and assuming a saturated thickness of 30 to 50 m (100 to 150 ft), the total amount of water in storage is estimated at 185 billion cu m (150 million acre-ft). 7) Annual recharge from precipitation has been calculated by the U. S. Geological Survey to be 20 to 23 mm (0.8 to 0.9 in), which is equivalent to some 530 million cu m (430,000 acre-ft). 15) The natural hydraulic gradient of the water table in the Ogallala is eastward, and ground water flows from the High Plains into Nebraska and Kansas. This underflow is estimated at 480 million cu m (390,000 acre-ft) per year. 16)

The number of irrigation wells tapping the Ogallala aquifer is estimated at over 3,000. Of these, 2,550 were located on the northern High Plains and irrigated over 81,000 ha or 200,000 acres in 1971. 17) Some 700 additional wells (as of 1966) were operating in the southern High Plains. Yields of wells range up to 125 l/s (2,000 gpm). However, in general, irrigation wells yielding 30 l/s (500 gpm) and over can only be developed where the saturated thickness is more than 16 m (50 ft). Total pumpage from the Ogallala aquifer is estimated at over 617 million cu m (500,000 acre-ft). In 1971, pumpage in the northern High Plains was 529 million cu m (429,000 acre-ft), an increase of 28 million cu m (23,000 acre-ft) over 1964. More than 148 million cu m (120,000 acre-ft) of ground water were utilized in the southern High Plains in 1965.

The rush from dry land to irrigated agriculture during the

1960's caused concern for over-pumpage and falling water levels. The number of irrigation wells was increasing rapidly, (the peak was reached in 1968 when some 390 irrigation wells were drilled), and ground-water pumpage was increasing sharply. Water levels declined as much as 5 m (16 ft) in some areas. To prevent excessively low water levels, similar to conditions now prevailing in the High Plains of New Mexico, Texas, and Oklahoma, economic studies were made and measures were taken to control ground-water development. The Colorado Water Conservation Board now denies well-permit applications in all areas where existing wells could be expected to deplete the saturated thickness by more than 40 percent in 25 years.[18] The "40 percent rule" has been adopted as the maximum depletion rate by the state and the High Plains Water Management Districts. As a result, since 1969, well drilling has dropped off sharply, and well permits can now only be obtained in a few isolated areas on the Colorado High Plains.

A network of 1,044 water-level observation wells was established in 1970 to monitor changes of storage in the Ogallala aquifer and to provide data for evaluation of water management plans using digital models. The network consists of 801 irrigation wells, 218 stock and domestic wells, and 25 U. S. Geological Survey observation wells. Seasonal water-level fluctuations vary as much as 5.5 m (18 ft). There is a net decline in water levels of about one m (3 ft) per year in areas of heavy pumpage.[17]

San Luis Valley -

The San Luis Valley is a large, north-trending structural basin downfaulted on the eastern border and covering some 7,800 sq km (3,000 sq mi). The valley is underlain by as much as 10,000 m (30,000 ft) of alluvium, volcanic deposits and lava flows, the latter frequently impeding the vertical movement of ground water. Ground water is obtained from unconfined and confined aquifers. Extensive clay beds ranging in thickness from 3 to 25 m (10 to 80 ft) divide the valley fill into an upper group of water-table aquifers and a lower group of artesian aquifers. The unconfined aquifer varies in thickness from 0 to 65 m (200 ft), and the artesian aquifers range in thickness from 17 m (50 ft) to hundreds of m or several thousand ft. The confining beds are, however, discontinuous and lenticular, and the water-table and artesian aquifers are connected hydraulically in varying degrees. The aquifers are tapped by an estimated 10,000 water wells, and the valley constitutes Colorado's largest single ground-water development.

The basin is drained by the Rio Grande, but the northern portion, called the "closed basin," is drained internally. The lowest part of this closed basin, covering some 650 sq km (250 sq mi), is known locally as the "sump". Inflowing surface and ground water applied for irrigation evaporates in this area.

Recent studies show that the San Luis Valley has an abundant supply of both surface and ground water. 19) The surface-water supply averages 1.9 billion cu m (1.5 million acre-ft) per year, and ground-water withdrawals average 925 million cu m (750,000 acre-ft) per year (period 1962-1967). In addition, the valley-fill sediments contain more than 2.5 trillion cu m (2 billion acre-ft) of water in storage, a quantity considered adequate to cover consumptive use for 1,000 years.

The principal source of water for irrigation is ground water, but until 1950 surface water was used exclusively. Lands in the eastern and central parts of the closed basin were irrigated by means of a network of canals, resulting in extensive waterlogging. Drainage systems to reclaim these lands were then constructed, but these proved only partially successful as they created similar problems further downstream.

In 1967, there were about 2,800 large capacity wells (yielding 20 l/s or 300 gpm and more), 2,160 of which tapped the water-table aquifer. The greatest concentration of these large-capacity wells is in the Rio Grande alluvial fan area north of Alamosa.

The total amount of ground water pumped per year is some 925 million cu m (750,000 acre-ft). Of this amount, 555 million cu m (450,000 acre-ft) is withdrawn by shallow, large-capacity irrigation wells; small-capacity wells in the confined aquifer contribute 370 million cu m (300,000 acre-ft). Approximately 7,000 small-capacity wells flow, uncontrolled, throughout the year, and it is estimated that some 185 million cu m (150,000 acre-ft) of water is wasted and needlessly contributes to waterlogging. Municipal and industrial water-supply wells pump a small quantity of water, with municipal water use at 3.6 million cu m (2,900 acre-ft) and industrial use at 420,000 cu m (340 acre-ft) in 1959. 7)

The Rio Grande alluvial fan, which is largely saturated, acts to regulate the water supply in the closed basin. Ground water withdrawn during periods of low surface-water flow is replenished during high-flow periods. Over the years, due to irrigation, the water level in the alluvial fan has risen above the level of the Rio Grande, causing the river to gain flow between Del Norte and Monte Vista. This rise in the water table has also created a ground-water divide north of and parallel to the Rio Grande. To the north of the divide, ground water moves toward the closed basin, and toward the south, it moves toward the Rio Grande.

Major water problems in the San Luis Valley are: 1) waterlogging, 2) waste of water by non-beneficial evapotranspiration, 3) deterioration of ground-water quality, and 4) failure of Colorado to deliver water to New Mexico and Texas in accordance with the Rio Grande Compact. Under the Compact of 1940 with New Mexico and Texas, certain quantities of water have to be delivered downstream, but since 1952, water deliveries have been deficient. The U. S. Bureau of Reclamation has proposed a plan to salvage water now lost by evapotranspiration in the closed basin and transport it to the Rio Grande. An electric analog model evaluation of such a water salvage plan has been prepared. 20) The U. S. Geological Survey is collecting basic data for preparing alternatives in water management, and a network of 334 observation wells has been established. The network consists of 184 irrigation wells; 31 stock, domestic and unused wells; and 119 U. S. Geological Survey observation wells.

Western Colorado -

This region takes in the western half of the state and includes the central highlands underlain by crystalline rocks and the sedimentary formations of the Colorado River basin. It is a sparsely populated region with a small water demand mainly for cattle watering, mining, lumbering, and tourism. Development of land and water resources in the region has been slower than in eastern Colorado due to limited availability of land suitable for irrigation, rugged topography, and climate. The occurrence and quality of ground water varies widely from aquifer to aquifer and with depth. Intensive ground-water investigations in the northwestern portion and in the Piceance Creek basin have been started in recent years. 21,22,23)

The mountainous area is composed of hard, dense igneous and metamorphic rocks that yield only small quantities of water to wells. Water is generally contained in the upper weathered and fractured zone. Several structural basins, so-called "parks" within the crystalline rocks, are underlain by alluvial and terrace deposits, and in some cases, by Tertiary sediments. Ground water is little utilized in these parks because streams are used for most water supplies.

Extensive urban development of the foothill and mountain regions near Denver has taken place in recent years. In these areas, practically all homes depend on individual wells for water supply. For this reason the crystalline rock is an important aquifer in spite of its low yield to wells.

Probably the most prolific aquifers are the valley-fill deposits along the rivers and streams, including the Yampa, Little Snake, Green, Colorado and Uncompahgre Rivers. Although the valleys are relatively narrow (less than 1.6 km or one mi), the sand and gravel beds yield moderate to large quantities of water to wells. Yields of 0.3 to 6 l/s (5 to 100 gpm) are common, and in deeper valleys, numerous wells yield as much as 60 l/s (1,000 gpm). 7) Most valley-fill aquifers are in hydraulic connection with adjacent streams, and large ground-water withdrawals reduce streamflow during dry periods.

The occurrence of ground water in the Green River Formation has been studied in the Piceance Creek basin, but elsewhere almost no information is available. Water is present in the fractures of the sandstone and in solution openings where mineral deposits have been leached by moving ground water. In the Piceance Creek basin, water stored in the leached zone amounts to 3 billion cu m (2.5 million acre-ft).

The Mesaverde Group of Cretaceous age is the thickest of the major aquifers. The rocks are composed of sandstone, shale, and thin to massive coal beds. Well yields range up to 40 l/s (600 gpm).

The Dakota Sandstone, widely present in the area, is composed of sandstones separated by shale beds. Well yields are generally less than 3 l/s (50 gpm), but wells tapping both the Dakota and the underlying Entrada Sandstone commonly yield more than 6 l/s (100 gpm).

The Leadville Limestone of Mississippian age lies at great depth below much of the region and locally supplies large quantities of ground water under high artesian pressure.

The use of ground water in western Colorado is small compared to the use of surface water. In the northern and central parts of western Colorado, ground-water withdrawal from some 4,000 wells was about 30 million cu m (24,700 acre-ft) in 1970. In the same year, 7.4 billion cu m (6 million acre-ft) of surface water was diverted, mostly for irrigation. 21)

Idaho

Idaho is a state of high mountains and plateaus situated west of the Continental Divide. Precipitation varies from 1,200 mm (48 in) per year in the Rocky Mountains along the Idaho-Montana border, to 400 mm (16 in) in the north and 200 mm (8 in) in the Snake River Plain. Major rivers are the Kootenai, Pend Oreille and Spokane Rivers in the north and the Snake River in the south. The average annual runoff is about 230 mm (9 in), which is equal to 142 million cu m per day (37 bgd), or 42 million acre-ft per year. 7) Three quarters of the runoff originating in Idaho is discharged by the Snake River which traverses southern Idaho and supplies large quantities of water for irrigation. Some 1.4 million ha (3.4 million acres) of land on the Snake River Plain are irrigated, and between 18 and 25 million cu m (15 and 20 million acre-ft) of river water is diverted per agricultural season. 24) Basaltic lava flows in the Snake River Plain and glacial outwash deposits in the Rathdrum Prairie-Spokane Valley area are the state's most important aquifers.

Ground water supplies 14 percent of the water demand for irrigation and a large percent of industrial, municipal, and domestic supplies. The total ground-water withdrawal was 9.7 million cu m/d (2.6 bgd) in 1970, 82 percent of which was used for irrigation. Ground-water withdrawal in the major drainage basins of Idaho is shown in Table 5. Ground-water use in Idaho is the highest of all states within the project area with total ground-water pumpage more than 25 percent larger than in Colorado. Recent trends in ground-water development suggest a decline in the rate of construction of new irrigation wells and an increase in the number of wells drilled for domestic and recreation home purposes, indicative of urbanization of former farmland. 26)

Problems involving ground water in the state are water-right conflicts, reduced streamflow resulting from large-scale ground-water development, waterlogging as a result of irrigation, water quality deterioration from agricultural runoff, and the discharge of industrial and municipal wastewaters. Concern is also being expressed about liquid waste disposal practices at the National Reactor Testing Station (NRTS).

Ground-water studies in the state are carried out by the U. S. Geological Survey in cooperation with the Idaho Department of Water Administration, by the Water Resources Institute at the University of Idaho, the Idaho Bureau of Mines and Geology, and the U. S. Atomic Energy Commission.

In this report, the state has been divided into the follow-

Table 5. IDAHO. ANNUAL WITHDRAWAL AND USE OF GROUND WATER IN MAJOR DRAINAGE BASINS. 25)

Purpose	Bear River Basin 1965 million m^3	Bear River Basin 1965 1,000 acre-feet	Panhandle Basins a) 1970 million m^3	Panhandle Basins a) 1970 1,000 acre-feet	Upper Snake River Basins 1970 million m^3	Upper Snake River Basins 1970 1,000 acre-feet
Irrigation						
Hectares (acres) irrigated (1,000)	-		4.5 (11)		307.6 (760)	
Withdrawal	185.0	150	40.7	33	2,960.4	2,400
Consumptive use	-	-	21.0	17	1,603.6	1,300
Industrial (self-supplied)						
Withdrawal	2.8	2.3	10.6	8.6	76.5	62
Consumptive use	0.1	0.1	0.5	0.4	3.8	3.1
Public Supplies						
Persons served (1,000)	-		23		180	
Withdrawal	5.6	4.5	6.8	5.5	61.7	50
Consumptive use	1.1	0.9	1.4	1.1	12.3	10
Rural-Domestic						
Persons served (1,000)	-		23		124	
Withdrawal	0.3	0.2	3.2	2.6	17.3	14
Consumptive use	0.1	0.1	1.6	1.3	8.6	7
Stock						
Withdrawn and used	0.4	0.3	0.2	0.12	7.4	6
Total withdrawal	190	160	620	50	3,120	2,530
Total consumptive use	-	-	250	20	1,640	1,330

a) Kootenai, Pend Oreille and Coeur d'Alene River Basins.

Table 5 (continued). IDAHO. ANNUAL WITHDRAWAL AND USE OF GROUND WATER IN MAJOR DRAINAGE BASINS. 25)

Purpose	Southwest Idaho Basins 1970		Salmon and Clearwater Basins 1970	
	million m^3	1,000 acre-feet	million m^3	1,000 acre-feet
Irrigation				
Hectares (acres) irrigated (1,000)	72.8 (180)		0.5 (1.2)	
Withdrawal	666.1	540	4.4	3.6
Consumptive use	407.1	330	2.2	1.8
Industrial (self-supplied)				
Withdrawal	45.6	37	2.8	2.3
Consumptive use	2.2	1.8	0.1	0.1
Public Supplies				
Persons served (1,000)	153		46	
Withdrawal	51.8	42	15.2	12.3
Consumptive use	10.4	8.4	3.1	2.5
Rural-Domestic				
Persons served (1,000)	102		32	
Withdrawal	12.8	10.4	4.4	3.6
Consumptive use	7.0	5.7	2.2	1.8
Stock				
Withdrawn and used	3.8	3.06	2.4	1.95
Total withdrawal	780	630	30	25
Total consumptive use	430	350	10	8

ing geographic areas: Kootenai and Pend Oreille River basins, Spokane-Coeur d'Alene River basin, Clearwater and Palouse River basins, Salmon River basin, Snake River basin and its various subdivisions, and the Great Basin. The location of principal aquifers and normal depths of wells are shown on Figure 9, and the range in yields of wells is indicated on Figure 10.

Kootenai and Pend Oreille River Basins -

The Kootenai and the Pend Oreille Rivers discharge large flows of water, much of it originating in Montana and Canada. A sizable underflow of ground water takes place along the Idaho-Washington border. 7) The glacial deposits in the valleys contain great quantities of ground water but use is relatively small. Springs or streams are tapped for water supply by most municipalities. In the upland area, domestic wells are drilled into the crystalline bedrock.

Spokane-Coeur d'Alene River Basin -

Large quantities of ground water are available from the glacial outwash deposits in the lowlands and in the river valleys. Studies on the Rathdrum Prairie indicate that more than 123 million cu m or 100,000 acre-ft of ground water flows annually into Washington through permeable sand and gravel deposits. 28) A portion of this ground water is believed to represent seepage from Pend Oreille Lake in the adjacent river basin. Damming of this lake has caused a water-table gradient of 30 to 80 cm/km (1.5 to 4 ft/mi) to the Washington state line, increasing to 60 to 240 cm/km (3 to 12 ft/mi) westward to Spokane. 29)

Ground-water levels on the Prairie are low, reflecting the high permeability of the gravel deposits. In spite of this, a considerable amount of ground water is used for industrial and municipal supply. Sprinkler irrigation from wells is also increasing.

Ground water in the Coeur d'Alene River basin is available from alluvial deposits varying in thickness from 0.3 to 100 m (one ft to several hundred ft). Most of the domestic supply comes from springs and creeks. 7) Waste from mining operations and ore processing along the South Fork portion of the basin has resulted in considerable surface-water pollution.

Clearwater and Palouse River Basins -

The Columbia River Group basalt, associated sedimentary

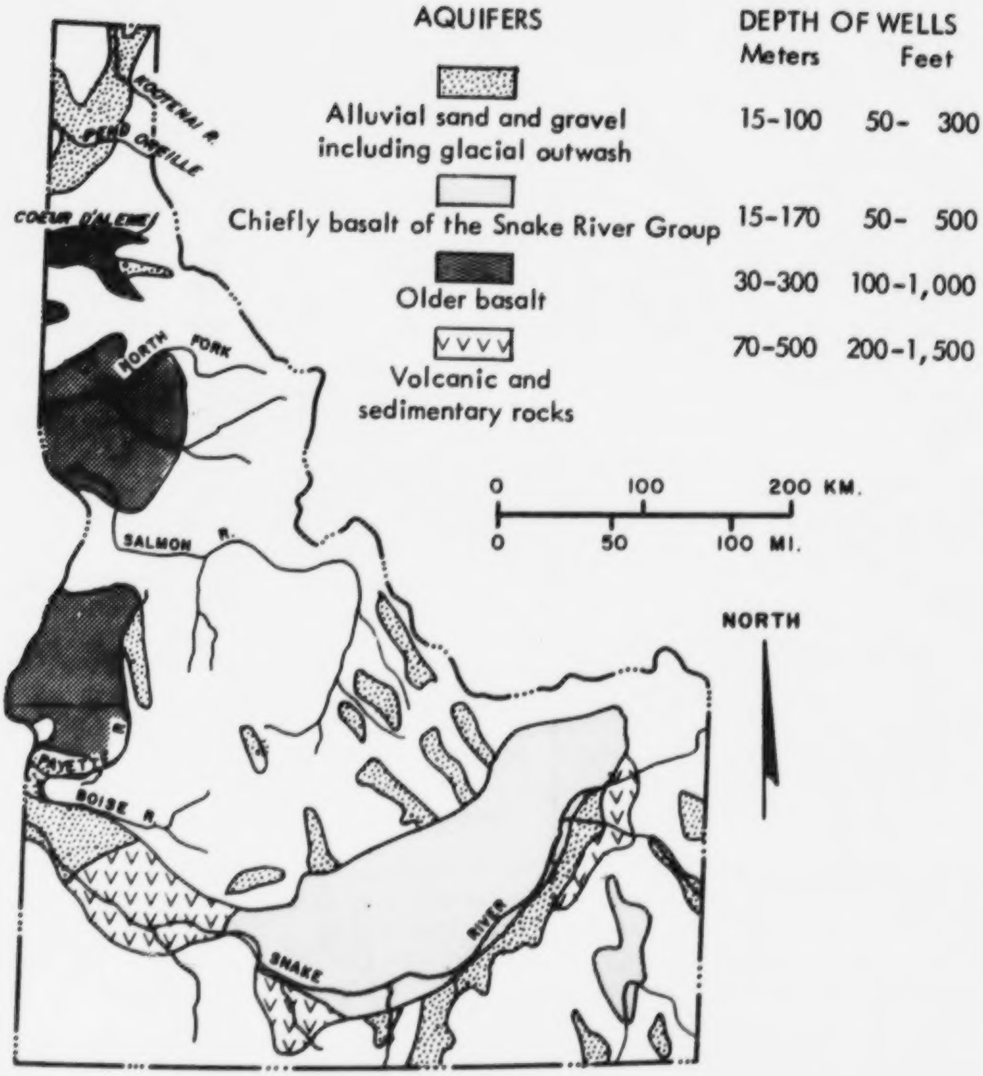

AQUIFERS
DEPTH OF WELLS
Meters
Feet
Alluvial sand and gravel including glacial outwash
15-100
50- 300
Chiefly basalt of the Snake River Group
15-170
50- 500
Older basalt
30-300
100-1,000
Volcanic and sedimentary rocks
70-500
200-1,500
0
100
200 KM.
0
50
100 MI.
NORTH
KOOTENAI R.
PEND OREILLE
COEUR D'ALENE
NORTH FORK
SALMON R.
PAYETTE
R.
BOISE R.
SNAKE
RIVER

Figure 9. Idaho - Major aquifers and depths of wells.[27]

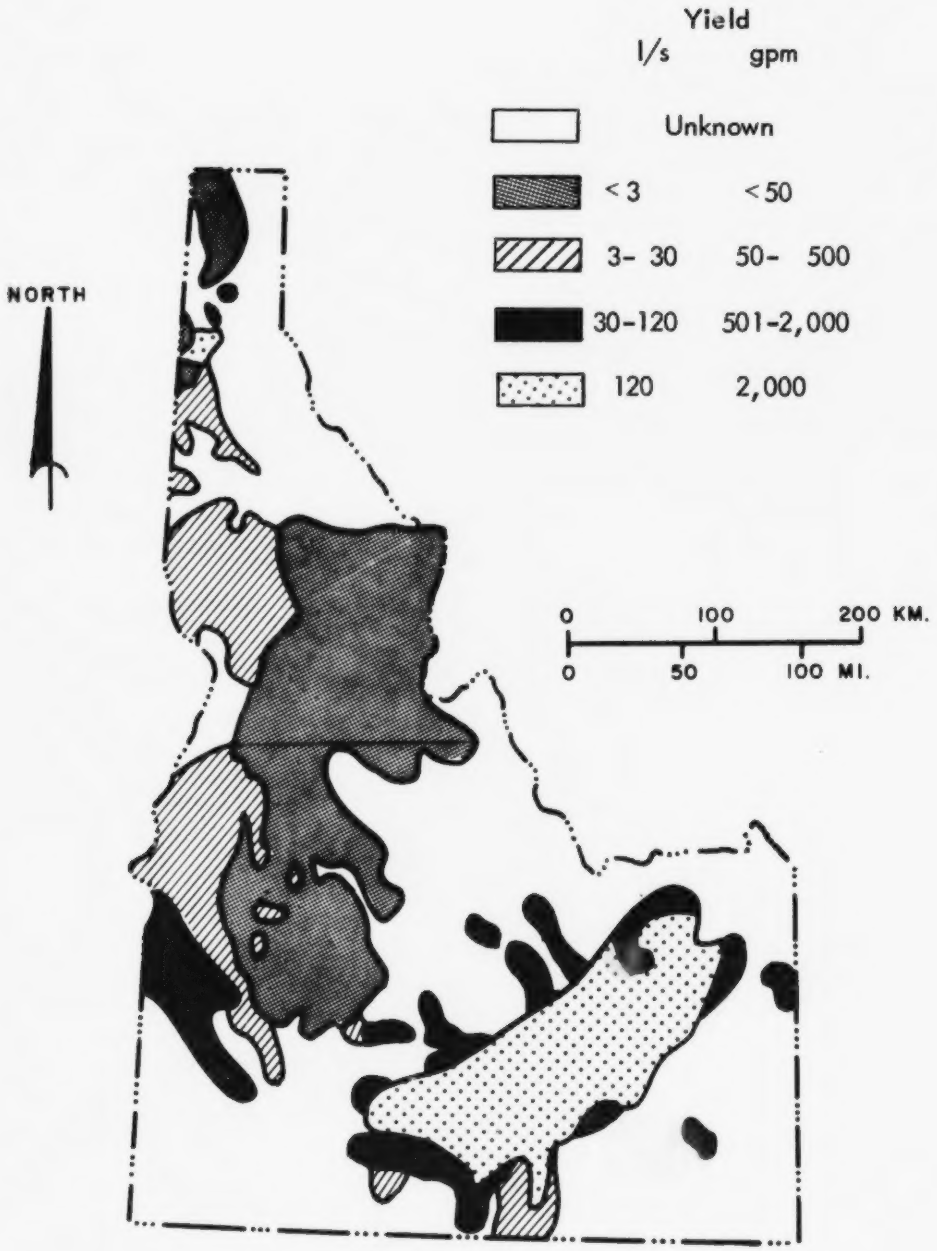

Yield
l/s gpm
Unknown
< 3 < 50
3- 30 50- 500
30-120 501-2,000
120 2,000
NORTH
0 100 200 KM.
0 50 100 MI.

Figure 10. Idaho - Range in yields of wells.[27]

rocks, and alluvium are the principal aquifers in these basins. Ground water is used for domestic, public, and industrial supply, but little information is available.

The Moscow Basin, an area of 150 sq km (60 sq mi) drained by the South Fork of the Palouse River, has potential water-supply problems because of rapid population increase. Ground water in the Moscow area is available from unconsolidated deposits and sands in the Latah Formation and from interbedded Columbia River basalt flows. The upper sediments are under water-table conditions, and the deeper aquifers are divided into an upper, middle, and lower artesian zone. Heads in the upper artesian zone declined 30 m (100 ft) over the years but are now rising due to decreased pumpage. 30,31) Prior to the early 1960's, all public supplies were obtained from the upper artesian zone, but since then pumpage has shifted to the deeper zones.

Ground-water pumpage in the Moscow Basin averaged about 88 l/s (2 mgd) during 1961-65 and is expected to double in the future. Recharge to the ground-water system is estimated to be about one-tenth of ground-water pumpage. Mathematical model studies of the aquifer, however, indicate that ground water in storage should meet water requirements for the next 50 to 100 years, and artificial recharge could prove to be a partial solution to future water problems.

In the upland areas, underlain by crystalline rocks of Precambrian (Belt Supergroup) and Cretaceous age, wells drilled for domestic supply yield only small quantities of water. 32)

Salmon River Basin -

The Salmon River and its tributaries cover a large portion of central Idaho. Principal aquifers are alluvial deposits in the river valleys and volcanic and associated sedimentary rocks. Water requirements are met mostly by tapping surface water, and as a result, ground-water resources are largely undeveloped.

Few ground-water studies have been made. In the Pahsimeroi River basin, alluvial sand and gravel deposits may be 1,000 m (3,000 ft) thick according to geophysical studies. The maximum thickness penetrated by wells is 120 m (350 ft). Irrigation wells tapping the alluvial aquifer yield as much as 240 l/s (3,850 gpm), and specific capacities range from 20 to 40 l/s/m (100 to 200 gpm/ft). 33)

Some 11,000 ha (27,000 acres) of land are irrigated; 9,900 ha (24,500 acres) by surface water and the remainder by ground water. Surface-water diversions in 1971 totaled 148 million cu m (120,000 acre-ft), and some 1.2 million cu m (930 acre-ft) of ground water was pumped. Other ground-water use, mostly for domestic purposes, is insignificant.

Snake River Basin -

About 86 percent of the population of the state is located in the Snake River basin, the largest in Idaho. Within the basin and its tributary valleys, almost 1.4 million ha (3.4 million acres) of agricultural land are irrigated with Snake River water. About 18.5 to 24.6 billion cu m (15 to 20 million acre-ft) of surface water is diverted for irrigation. The river is an important resource for hydro-electric power generation and for navigation. Flow is regulated by numerous dams and reservoirs, and total storage capacity of reservoirs is some 12.3 billion cu m (10 million acre-ft). Some 20 power and multi-purpose dams are presently operating, under construction, or authorized.

Ground water in the Snake River basin supplies over 70 percent of the water needs of 200 municipal water-supply systems and about 100 industrial plants. Some 1.4 million cu m/d (360 mgd) of water are used for these purposes. In 25 years, the joint municipal-industrial demand will increase to over 3.8 million cu m/d (1,000 mgd). Ground-water conditions in the main river valley and in several tributary river basins have been studied. Because local hydrogeologic conditions vary from place to place, these regions will be discussed separately. The various ground-water areas within the basin are shown on Figure 11.

The Weiser and Payette River basins are located in the west-central portion of the Snake River drainage basin. Ground water is obtained from the Columbia River Group basalt and from valley-fill deposits. Ground water is used for drinking and industrial supply and for irrigation. In 1960, ground-water use for irrigation was 62 million cu m (50,000 acre-ft) in the Weiser Valley and 74 million cu m (60,000 acre-ft) in the Payette Valley. 7)

The Boise-Nampa area in the western portion of the Snake River basin is undergoing a rapid change due to increased urbanization. Population rose from 97,800 in 1953 to 134,000 in 1970, and ground-water use has increased considerably. Shallow aquifers are terrace gravels, Quaternary alluvium, and basalts of the Snake River Group. These formations act as a single hydrologic unit and individual well yields are high. The Glenns Ferry Formation of the Idaho Group is the deep aquifer in the area. This unit is com-

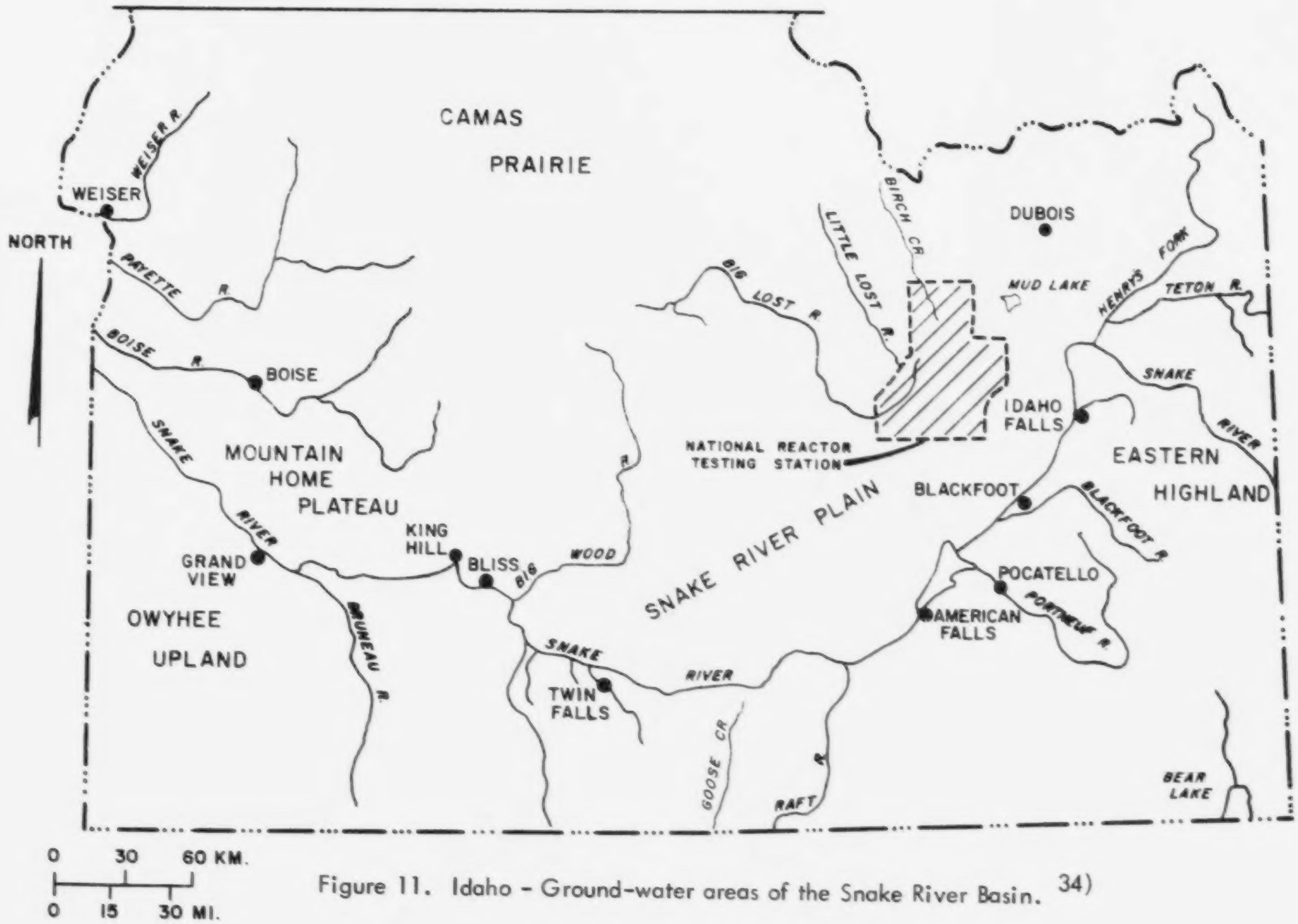

NORTH
CAMAS
PRAIRIE
WEISER
WEISER R.
PAYETTE R.
BOISE R.
BOISE
SNAKE
RIVER
MOUNTAIN
HOME
PLATEAU
GRAND
VIEW
OWYHEE
UPLAND
BRUNEAU R.
KING
HILL
BLISS
BIG
WOOD
R.
SNAKE
RIVER
TWIN
FALLS
GOOSE CR.
RAFT
R.
SNAKE RIVER PLAIN
BIG LOST R.
LITTLE LOST R.
BIRCH CR.
NATIONAL REACTOR
TESTING STATION
DUBOIS
MUD LAKE
HENRYS FORK
TETON R.
SNAKE
RIVER
IDAHO
FALLS
EASTERN
HIGHLAND
BLACKFOOT
BLACKFOOT R.
POCATELLO
PORTNEUF R.
AMERICAN
FALLS
BEAR
LAKE
0
30
60 KM.
0
15
30 MI.

Figure 11. Idaho - Ground-water areas of the Snake River Basin. 34)

posed of continental beds of clay, silt, sand, and fine gravel, and locally contains volcanic ash and lava flows. Its total thickness is about 600 m (2,000 ft). The aquifer can be found at relatively shallow depth below much of the area. The terrace gravels overlying the Glenns Ferry Formation have a total thickness of 50 m (150 ft), and the Snake River Group basalt beds have a maximum thickness of 100 m (300 ft). Alluvial deposits present in the floodplain have a thickness of about 17 m (50 ft).

Application of surface water to farmland on the terraces and floodplain of the Boise River for over 60 years has raised ground-water levels and has increased the amount of ground water held in storage. In 1970, only 12,500 ha (31,000 acres) in the Boise-Nampa area were irrigated by ground water. Pumpage for irrigation was 115 million cu m (93,000 acre-ft), all obtained from the deep aquifer. The same aquifer supplied 33 million cu m (26,800 acre-ft) of water for domestic and stock use and 19 million cu m (15,100 acre-ft) for industrial use. The shallow aquifer was only used for domestic and stock use and supplied 13 million cu m (10,700 acre-ft). 35) The shallow aquifer is recharged mainly by irrigation returns, and in 1970, this recharge amounted to an estimated 617 million cu m (500,000 acre-ft) of water. Most of this water was surface water, but a portion was obtained from irrigation wells tapping the deep aquifer. This large volume of water applied to the shallow aquifer has caused chronic waterlogging problems.

In southern Canyon County, permeable sands of the Idaho Formation are the principal aquifers with yields of as much as 100 l/s (1,600 gpm) to pumped wells. 36) Perched ground water occurs locally. The Snake River Basalt is above the water table in most of the area, but where saturated, it yields water freely. In 1960, some 1,200 ha (3,000 acres) were irrigated by ground water in the Dry Lake area. Well depths ranged from 65 to 400 m (200 to 1,200 ft). Yields vary widely because of variations in lithology and well construction. Upward leakage of artesian water has caused waterlogging south of Melba, and high water-table conditions and drainage problems occur south of Lake Lowell.

The Owyhee upland in the southwest corner of the state is drained by the Snake and Owyhee Rivers. Ground water is available from volcanic rocks, sediments of the Idaho Group, and valley-fill material; but there are few wells, and pumpage is small.

The Mountain Home Plateau is a rolling upland plain located between the Boise Valley and the Snake River valley. Ground water is generally found at depths exceeding 100 m (300 ft) in the Snake River and Idaho Groups, which consist of alternating basalt and gravel beds. Locally, perched ground water is available at shallower depth. Ground water is utilized for rural and domestic use, but supplies are considered insufficient for large-scale irrigation because of the low rate of recharge. Well development is concentrated in the Kuna area in Ada County and near the Mountain Home Air Force Base in Elmore County. Wells in the Kuna area are less than 300 m (1,000 ft) deep and generally yield more than 60 l/s (1,000 gpm). 37) Yields of wells in the Air Base area range between 30 and 120 l/s (500 and 2,000 gpm).

Ground water in the Snake River valley from the Oregon state line upstream to the town of Bliss is obtained from basalt, the Idaho Group, silicic volcanic rocks and alluvial deposits. Unconfined ground water is a minor source of irrigation water. In the Bruneau-Grand View area, artesian water confined in the volcanic rocks is widely used for irrigation, and deep wells yield from 30 to 250 l/s (500 to 4,000 gpm). Pumpage for domestic use and irrigation was about 2.5 million cu m/d (1,000 cfs) in 1969. Conditions for large-scale development of ground-water resources are excellent except in the Bruneau-Grand View area where the use of artesian water is severely limited by its chemical quality. In addition, overpumping is causing local water-level declines. 38)

In Camas Prairie, an intermontane basin along the north flank of the Snake River Plain with an area of about 780 sq km (300 sq mi), ground water is obtained from alluvial fill and basalt. Water in the shallow deposits is under water-table conditions and the water table is less than 3 m (10 ft) below the surface. The deeper sand and gravel aquifer is divided into an upper and lower horizon. These units are artesian and many of the deeper wells flow. Basalt interfingers with alluvial deposits and is an important aquifer in the east and southeast. The maximum thickness of the valley fill is 170 m (500 ft). Irrigation wells tapping sand and gravel beds yield 30 to 75 l/s (500 to 1,200 gpm). Wells drilled in basalt will yield 120 to 190 l/s (2,000 to 3,000 gpm).

Ground water is used for domestic, stock, and municipal supplies and for irrigation. Total pumpage in 1960 was about 2.5 million cu m (2,000 acre-ft). Calculations indicate that some 14.8 million cu m (12,000 acre-ft) of ground water can safely be withdrawn each year. Large-scale development of ground water would lower the water table considerably and would affect the present practice of subirrigation. 39)

The Wood River basin, located east of the Camas Creek basin and north of the Snake River Plain, is drained by the Big Wood and Little Wood Rivers. Ground water is found in fluvioglacial deposits that reach a thickness of over 100 m (300 ft) in places. Some wells in the Carey area tap the basalt aquifer. Water levels are generally less than 13 m (40 ft) below the surface. Artesian sand and gravel zones in the Big Wood River valley are found 40 to 50 m (125 to 150 ft) below land surface. Ground water is used for domestic, stock, municipal and irrigation supplies. In 1960, some 43 million cu m (35,000 acre-ft) was pumped for irrigation.

The basins of Big Lost River, Little Lost River, and Birch Creek lie along the northern edge of the Snake River Plain east of the Little Wood River basin. There is no surface-water runoff in these basins, as all water infiltrates into alluvial deposits and basalt (lower Big Lost River valley) and drains southward toward the Snake River. The alluvial deposits near the mouth of the Big Lost River valley are over 100 m thick and transmit large quantities of ground water, estimated at several hundred million cu m/yr. The water table is generally close to the surface, and in some areas, the occurrence of ground water is complex because of multiple perched aquifers resulting from irrigation and percolation (Arco, Butte City). Moderately large to large yields can be developed from wells 30 to 65 m (100 to 200 ft) deep. Specific capacities in the Arco area, located to the east of the mouth of the Big Lost River valley, range from 40 to 80 l/s/m (200 to 400 gpm/ft).

Wells drilled in the Little Lost River valley are generally less than 50 m (150 ft) deep and are mostly used for irrigation. Yields range from 30 to 60 l/s (500 to 2,500 gpm).

Little information on ground water is available regarding the Birch Creek basin, but underflow is estimated at 86 million cu m (70,000 acre-ft) per year. Ground-water withdrawal in 1960 was about 62 million cu m (50,000 acre-ft) in the Big Lost Valley and 49 million cu m (40,000 acre-ft) in the Little Lost Valley. Conditions for large-scale development of ground-water resources are excellent; however, conflicts over surface-water rights could arise in places.

In the Mud Lake basin at the northeast end of the Snake River Plain, the principal aquifer is the Snake River basalt and associated cinder beds. Hundreds of wells are used to irrigate many thousands of hectares of land. The basalt is extremely permeable, and well yields range from 125 to 570 l/s (2,000 to 9,000 gpm) with drawdowns of less than one m.

North of Mud Lake, the basalt is at the surface, and the land is not suitable for irrigation. Well fields drilled in this area discharge water into canals and distribute the water to irrigated land to the west and southwest. Ground water moves from the Mud Lake area toward the Snake River Plain. This underflow is estimated at over 370 million cu m (300,000 acre-ft) per year. Ground water is also used for domestic, stock, and municipal supplies. Total pumpage in 1960 was about 370 million cu m (300,000 acre-ft). 7)

In the Twin Falls district on the southwest side of the Snake River Plain, ground water is obtained from basaltic and silicic rocks and from sand and gravel beds. The water is at shallow depth near the mountains but is deeper than 165 m (500 ft) near Salmon Falls Creek. Ground water is used extensively for public supply and also for domestic, stock, and irrigation. The total pumpage in 1960 was about 43 million cu m (35,000 acre-ft). Additional supplies of ground water could be developed. In the Twin Falls tract, ground-water levels have risen over 30 m (100 ft) as a result of irrigation with Snake River water. Most of the wells in this area obtain water for irrigation from shallow aquifers. 40) Underflow in buried channels in the Salmon Falls area is at least 31 million cu m (25,000 acre-ft) per year. 41)

The basins of Dry, Cottonwood, Goose, Rock and Marsh Creeks are located east of the Twin Falls district on the south side of the Snake River Plain. Ground-water conditions are quite variable, but principal aquifers are alluvial deposits, basalt of the Snake River Group, silicic volcanic rocks, and limestone. In the Dry Creek area, 250 wells supplied irrigation water to about 6,000 ha (15,000 acres) in 1959. Artesian aquifers are considered fully developed, but more ground water could be developed from the Snake River basalt. 42)

In the Goose Creek and Rock Creek basins, yields range from 12 to 190 l/s (200 to 3,000 gpm) in the basalt and silicic rock aquifers, and from 12 to 70 l/s (200 to 1,100 gpm) in the alluvial aquifers. Pumping lifts are as high as 150 m (450 ft). About 430 wells withdrew 228 million cu m (185,000 acre-ft) of ground water for irrigation in the 1961-1965 period. 43) Total pumpage for irrigation in all areas was about 308 million cu m (250,000 acre-ft) in 1960.

In the Raft River basin in south-central Idaho, the alluvial deposits form the main aquifer in the central and southern part of the valley. The basalt of the Snake River Group is the principal aquifer at the north end. Ground water is used for domestic, stock, and irrigation supply. 44) In 1966, about 28,000 ha (69,000 acres) were irrigated partly or wholly with ground water, and some 290 million cu m (235,000 acre-ft) of ground water was pumped. The valley was closed to further ground-water appropriation as of July 1963 because of declining water levels. 45)

Further east, in Oneida and Power Counties, including the Curlew, Arbon and Pocatello areas, well development is mostly for domestic and stock use. About 19 million cu m (15,000 acre-ft) per year is pumped from a sand and gravel aquifer in the Curlew valley. 46)

In the Eastern Highlands, that lie to the east and southeast of the Snake River Plain, ground water is found in alluvium, basalt of the Snake River Group, and silicic volcanic rocks. Alluvial aquifers in the lowlands supply large quantities of water, and well yields range from 30 to 60 l/s (500 to 1,000 gpm). 47) In 1960, some 123 million cu m (100,000 acre-ft) of ground water was pumped for irrigation, chiefly in the Michaud Flats, Pocatello, Rigby and Rexburg areas. Ground water is also used for domestic, municipal, and industrial supplies.

In the Portneuf River basin, the quantity of ground water pumped for irrigation was about 37 million cu m (30,000 acre-ft) in 1970. Principal aquifers are alluvial deposits and basalt beds. 48)

The Snake River Plain, a broad undulating surface of about 26,000 sq km (10,000 sq mi), extends for about 400 km (250 mi) along and mainly north of the Snake River in southeastern Idaho. The Plain is a great structural depression filled with a series of basalt flows alternating with beds of pyroclastic and sedimentary materials, which constitute one of the world's most productive aquifer systems. At the surface, the boundaries of the aquifer are formed by the contact with less permeable and complex rock formations surrounding the Plain. At depth, the boundary of the aquifers is not known, as no well has been drilled through the entire rock sequence. The aquifer is several hundreds of meters thick except near the edge of the plain.

The storage capacity of the aquifer is huge and estimated at hundreds of billions of cubic meters. Water is contained within interflow zones (between lava flows), clinker openings (formed at lava flow surface when cooling), shrinkage cracks (resulting from cooling), lava tubes (formed by liquid lava flowing out beneath solidified crust), and vesicles (pores formed by expansion of gases during cooling).

These openings are interconnected and make the aquifer highly permeable. Well yields of 120 to 300 l/s (2,000 to 5,000 gpm) are common. Typically, an irrigation well is drilled for each 65 to 260 ha (160 to 640 acres) of land to be irrigated and is pumped at 55 to 225 l/s (900 to 3,600 gpm). 7)

Centers of population, agricultural development, and water use are mostly near the Snake River which flows along the southern and eastern margins of the Plain. Cropland near the river is practically all irrigated with Snake River water while land further from the river is irrigated with ground water. In 1965, an estimated 600,000 ha (1,500,000 acres) were irrigated - 360,000 ha or 900,000 acres with surface water and 240,000 ha or 600,000 acres with ground water. 42,49)

The Snake Plain aquifer also supplies 100 percent of the domestic water needs in the region. 50) Recharge to the aquifer is huge. About 4.9 billion cu m (4 million acre-ft) of water is recharged to the aquifer annually as a result of irrigation from surface-water sources while 1.4 billion cu m (1,100,000 acre-ft) of the ground water pumped returns to the aquifer. 49)

The Snake Plain aquifer is recharged by precipitation, infiltration from irrigation water, seepage from streams, underflow from tributary basins, and wastewater introduced into drain wells. Ground-water flow is toward the Snake River and discharges along the valley in large springs. Some 70 cu m/sec (1.8 million acre-ft/yr) of ground water flows into the Snake River in the stretch between the Blackfoot River and the Raft River, and some 185 cu m/sec (4.7 million acre-ft/yr) enters the river between Milner Dam and Bliss. 7)

In spite of the fact that the Snake Plain aquifer has been studied extensively in the last 70 years, many uncertainties still remain due to complex hydrogeologic conditions. Only tentative evaluation of aquifer characteristics is possible. The use of modeling to study the aquifer is now in process. 50)

The National Reactor Testing Station (NRTS) covers 2,300 sq km (890 sq mi) of desert and basalt fields on the eastern Snake River Plain. Numerous ground-water investigations have been made in this area by the U. S. Geological Survey and the Atomic Energy Commission. Most of the ground water contained in the Snake Plain aquifer below the site originates as underflow from the northeastern part of the Plain and from adjacent drainage areas to the west and north.

This estimated underflow beneath the NRTS is 78 cu m/sec, equivalent to 4.7 x 10^{11} gal/yr. 51) The ground water moves southward through the aquifer and discharges through springs along the valley of the Snake River near Hagerman.

The rocks below the NRTS site consist of about 1,600 m (5,000 ft) of basaltic volcanic rock interbedded with alluvial sediments. Interbedded sedimentary rocks within the basalt act as aquifers or aquicludes depending on their permeability. Fractures, cavities, and lava tubes form passageways for ground-water movement. Floodplain deposits varying in thickness from a few cm to over 20 m (50 ft) are present over most of the Station. These deposits consist mostly of coarse sand and gravel and are highly permeable. The depth to water within the NRTS boundaries ranges from 65 m (200 ft) in the northeast to 270 m (900 ft) in the west-southwest. 52)

Water for NRTS facilities is obtained from 24 wells tapping the Snake Plain aquifer. The water is used for reactor cooling, washing, chemical processing, and drinking. Pumpage for all facilities in 1970 was 10 million cu m (2.6 billion gallons) or roughly 310 l/s (4,900 gpm). About half of this amount, 4.5 million cu m or 1.2 billion gallons, was returned to the ground through wells and ponds. 51)

Much additional ground water can be pumped in the Snake River Plain, but increased consumptive use may cause a decrease in streamflow and may conflict with established water rights. Studies of artificial recharge of ground water are underway. 49)

Great Basin -

An area of several hundred sq km of southeasternmost Idaho forms part of the Great Basin drainage system. The area is drained by the Bear and Malad Rivers which flow southward into Utah. Ground water is encountered in alluvium, sedimentary rocks, and in basalt of the Snake River Group. Ground-water use for irrigation was 148 million cu m (120,000 acre-ft) in 1960 and applied to 16,000 ha (40,000 acres) of land. Ground water is also used for domestic, stock, municipal, and industrial use. Well yields are as high as 155 l/s (2,500 gpm) from the alluvium and 220 l/s (3,500 gpm) from the basalt. 53)

Montana

Montana, the largest state within the project area, is a region of mountains, intermontane valleys, and plains. Precipitation averages about 380 mm (15 in) but varies from 1,140 mm (45 in) or more in the Rocky Mountains to less than 250 mm (10 in) in the south-central Plains area. The eastern three-fourths of the state is part of the Great Plains and is drained by the Missouri and Yellowstone Rivers and their tributaries. The region west of the Continental Divide is drained by the Kootenai and Clark Fork Rivers and their tributaries. The total river flow leaving the state is estimated at 139 cu hm/d (36 bgd), or 41 million acre-ft per year. Of this amount, some 27 cu hm/d (8.1 million acre-ft) is received from Canada in the Kootenai and Flathead Rivers and 16 cu hm/d (4.8 million acre-ft) enters the state from Wyoming in the Yellowstone and Bighorn Rivers.

Surface-water runoff differs sharply from west to east. In the mountainous western portion the average annual runoff varies from 125 to 1,000 mm (5 to 40 in), but in the plains it is less than 25 mm (one in), except for isolated mountain ranges. In the Plains area, rainfall is sufficient only for stock raising and dry farming. The Missouri and Yellowstone Rivers and principal tributaries are extensively used for irrigation, and the chemical quality of the rivers is deteriorating. 54)

Only a small part of the available water resources is used within the state. The population is roughly 700,000, and the total water use of 1.2 million cu m/d (308 mgd) in 1970 for public, rural, and industrial supplies is low compared to that of the other project states. Irrigation is the major water use. In 1970, some 2.9 million cu m (7.7 billion gallons) per day of water was used to irrigate 890,000 ha (2.2 million acres).

Serious conflicts between agricultural and potential industrial water users are occurring in eastern Montana. Development of major coal reserves in the basin is planned, and coal and utility companies have requested more than 4.1 billion cu m (3.3 million acre-ft) per year of surface water. The Yellowstone River has an average annual flow of about 11.1 billion cu m (9 million acre-ft) and a low flow during dry years of about 3.2 billion cu m (2.6 million acre-ft). Existing water rights for irrigation amount to 2.8 billion cu m (2.3 million acre-ft). Thus, the industrial requirements cannot be met. 55) In order to determine water allocations, a three-year ban on the issuance of water permits in the Yellowstone River basin was put into effect in March 1974. In western and central Montana mountain valleys, there is a noticeable shift of land and water resources from agricultural to recreational-residential uses as land is developed. 56)

Because of the readily available surface-water sources in most areas of the state, ground water plays a minor role. Only 2 percent of the total water used in the state is obtained from wells, mostly for public, rural, and industrial supplies. Total ground-water use in 1970 was 564,000 cu m/d, the lowest of the six states. All indications are that the use of ground water will increase sharply in future years. Enormous quantities of water stored in deep aquifers can be developed for use.

Principal aquifers are unconsolidated valley-fill and glacial deposits, and permeable sedimentary rocks. Buried valleys containing sand and gravel deposits are numerous. 57) The Plains are underlain by gently eastward-dipping sedimentary rocks of Cenozoic, Mesozoic, and Paleozoic age, interrupted by structural basins and domes. The area roughly north of the Missouri River is mantled by glacial drift. The bedrock geology and principal preglacial drainage courses are shown on Figure 12. The ground-water potential of major unconsolidated aquifers is indicated on Figure 13.

Some 42,300 water wells were inventoried in the state in 1967; of these, about 38,800 were utilized for domestic and stock use (see Table 6). The quality of ground water is generally excellent to good in western Montana and good to poor in the eastern part of the state.

The U. S. Geological Survey, the Montana Bureau of Mines and Geology, and the Montana Water Resources Board are the principal agencies that have made ground-water studies in the state. In recent years, the Montana University Joint Water Resources Research Center has also carried out some ground-water investigations.

Unconsolidated Aquifers -

Alluvium, terrace deposits, and glacial deposits form excellent aquifers. Alluvial fill in intermontane valleys in the west and deposits along the principal rivers in the central and eastern portion of the state are capable of yielding large quantities of water to wells. Some 35 major regions or valleys underlain by one or more unconsolidated aquifers have been identified. 57) The permeable thickness of these unconsolidated deposits ranges from 7 m (20 ft) to over 100 m (300 ft), and the saturated thickness ranges from 3 m (10 ft) to 70 m (200 ft). Valley aquifers are not thick, 3 to 10 m (10 to 30 ft), but are highly permeable and generally in hydraulic connection with the adjacent river.

Principal areas of actual and potential ground-water devel-

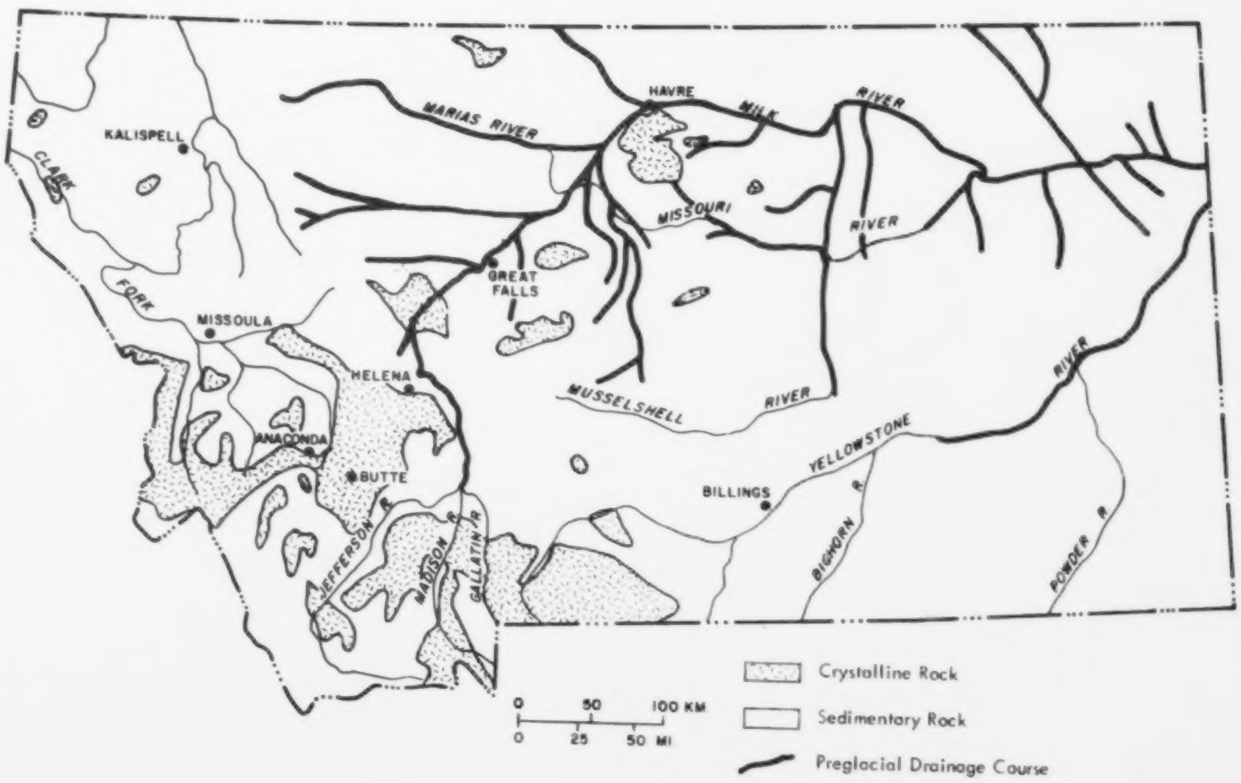

KALISPELL
CLARK
FORK
MISSOULA
MARIAS RIVER
HAVRE
MILK
RIVER
MISSOURI
RIVER
GREAT FALLS
HELENA
ANACONDA
BUTTE
JEFFERSON R
MADISON R
GALLATIN R
MUSSELSHELL
RIVER
BILLINGS
YELLOWSTONE
RIVER
BIGHORN R
POWDER R
0 50 100 KM
0 25 50 MI
Crystalline Rock
Sedimentary Rock
Preglacial Drainage Course

Figure 12. Montana - Bedrock geology, major rivers, and pre-glacial drainage courses. 57)

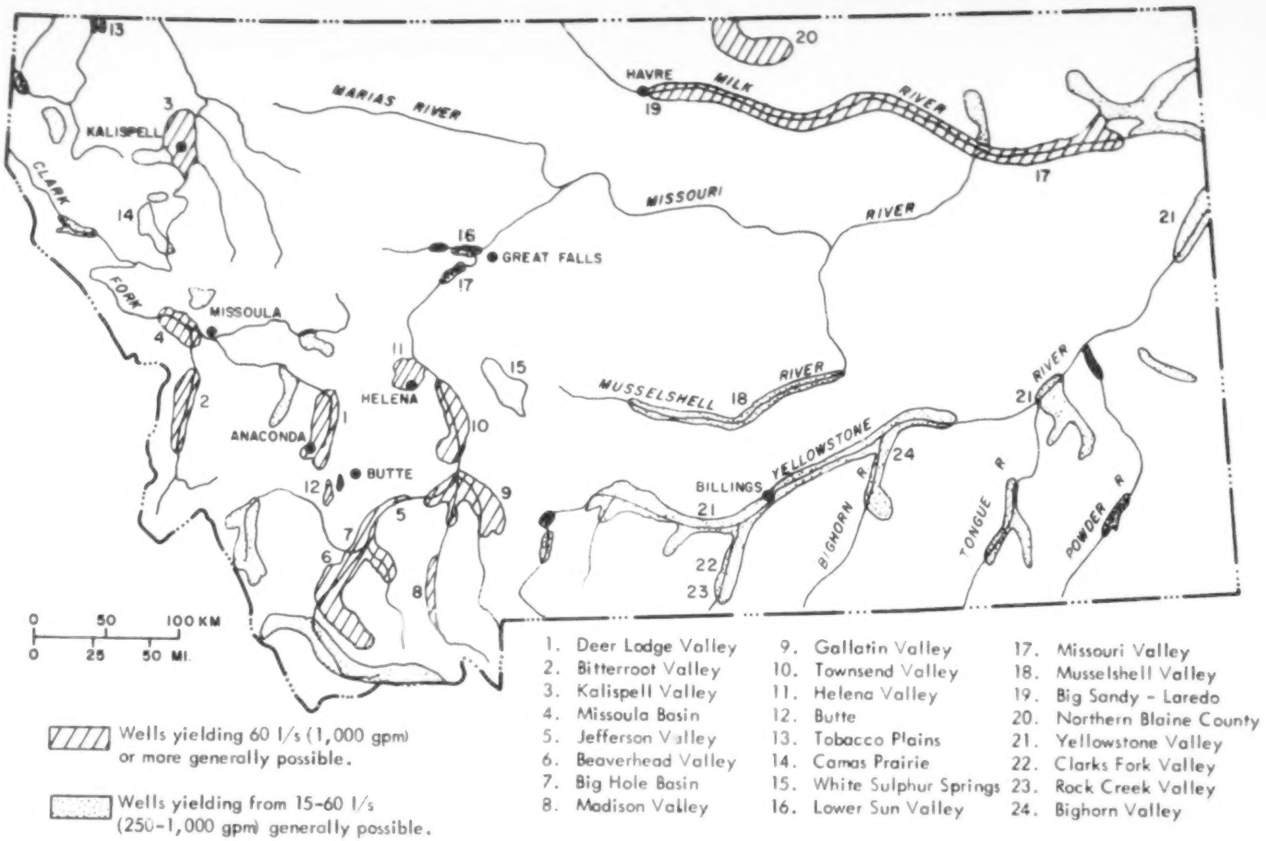

13
20
HAVRE
MILK
RIVER
19
MARIAS RIVER
3
KALISPELL
CLARK
14
MISSOURI
RIVER
17
21
16
GREAT FALLS
17
FORK
MISSOULA
4
11
HELENA
15
MUSSELSHELL
18
RIVER
2
ANACONDA
1
10
YELLOWSTONE
24
RIVER
21
12
BUTTE
9
BILLINGS
21
BIGHORN
R
TONGUE
R
POWDER
R
5
7
6
8
22
23
0
50
100 KM
0
25
50 MI.
Wells yielding 60 l/s (1,000 gpm) or more generally possible.
Wells yielding from 15-60 l/s (250-1,000 gpm) generally possible.
1. Deer Lodge Valley
2. Bitterroot Valley
3. Kalispell Valley
4. Missoula Basin
5. Jefferson Valley
6. Beaverhead Valley
7. Big Hole Basin
8. Madison Valley
9. Gallatin Valley
10. Townsend Valley
11. Helena Valley
12. Butte
13. Tobacco Plains
14. Camas Prairie
15. White Sulphur Springs
16. Lower Sun Valley
17. Missouri Valley
18. Musselshell Valley
19. Big Sandy - Laredo
20. Northern Blaine County
21. Yellowstone Valley
22. Clarks Fork Valley
23. Rock Creek Valley
24. Bighorn Valley

Figure 13. Montana - Ground-water potential of major unconsolidated aquifers. 127)

Table 6. MONTANA. USE OF WATER WELLS, 1967.[57)]

Use	Number of Wells
Public Supply	608
Domestic	12,977
Irrigation	1,417
Industrial	402
Stock	14,846
Domestic and Stock	10,945
Commercial	293
Air conditioning, dewatering, fire protection	42
Institutional	144
Unused	192
Unknown	446
Total:	42,312

opment from unconsolidated aquifers in western Montana are: Deer Lodge Valley, Bitterroot Valley, Kalispell Valley, Missoula Basin, Jefferson and Beaverhead Valleys, Big Hole Basin, Madison River valley, Gallatin Valley, Townsend Valley, Helena Valley, Butte area, Tobacco Plains, Camas Prairie, White Sulphur Springs area, and the Lower Sun River valley. In eastern Montana the principal areas are: Missouri River valley, Musselshell River valley, Big Sandy-Laredo area, northern Blaine County, Yellowstone Valley, Clarks Fork and Rock Creek Valleys, and the Bighorn Valley. Potentially productive deposits of permeable and saturated sand and gravel beds occur in drainage channels of the former Missouri River system.

In the Deer Lodge Valley, a structural basin filled with over 1,600 m (5,000 ft) of unconsolidated material of Tertiary and Recent age, ground water is pumped by more than 225 wells. Well yields range up to 60 l/s (1,000 gpm). The aquifer consists of sand and gravel beds within the upper section of the valley fill. Deeper artesian aquifers are also present. Agriculture and ore processing are the principal industries. Ground-water use for industrial, municipal, stock, domestic, and irrigation was 8.6 million cu m (7,000 acre-ft) in 1967. Evapotranspiration and pumpage cause a seasonal lowering of the water table of as much as 3 m (10 ft), but each spring, the Clark Fork River, irrigation seepage, and infiltration from precipitation replenish the ground-water reservoir. 58)

The Bitterroot Valley, an intermontane basin located south of Missoula, contains extensive saturated alluvium and Tertiary deposits that are tapped by over 85 wells. Average saturated thickness of the aquifer is some 13 m (40 ft), and well yields range from 15 to 60 l/s (250 to 1,000 gpm). Most of the ground water is used for stock and domestic purposes. About 20 wells irrigate 480 ha (1,200 acres). Large amounts of additional ground water can be developed as adequate recharge is available. 59,60)

The Kalispell Valley in northwestern Montana is an intermontane basin with several aquifers of Pleistocene and Recent age within the upper 200 m (600 ft) of the valley fill. Principal aquifers are a deep artesian, a shallow artesian, and a floodplain gravel formation. These aquifers are tapped by more than 450 wells that range in depth from 10 to 150 m (30 to 450 ft) and in yield from 0.3 to 190 l/s (5 to 3,000 gpm). The floodplain gravel aquifer is about 10 m (30 ft) thick and yields 1.4 million cu m (1,100 acre-ft) of water per year. Its average transmissivity is 1,400 sq m/d (1,100,000 gpd/ft). 61) A saturated and confined zone of sand and gravel occurring throughout the valley is termed the deep artesian aquifer. It is tapped by more than 200 wells (some flowing), ranging in depth from 30 to 160 m (100 to 500 ft). Development of this deep sand and gravel zone is accelerating because it is little affected by drought and because of poor water quality in shallower aquifers.

Alluvial deposits within the Clark Fork and Ninemile Valleys in the Missoula Basin are tapped by more than 275 wells, mostly for domestic and stock supplies. The aquifer has an average thickness of 65 m (200 ft), and well yields are reported to be as high as 315 l/s (5,000 gpm). Pumpage was 30 million cu m (24,000 acre-ft) in 1963. 62)

Alluvial deposits along the Jefferson River, its upstream extension (the Beaverhead River), and major tributaries in southwestern Montana contain relatively thin but important aquifers. Average thickness is 6 to 8 m (20 to 25 ft), and well depths range from 3 to 55 m (10 to 170 ft). Most well yields are in the 0.3 to 2 l/s (5 to 30 gpm) range, but some large-capacity wells yield 95 l/s (1,500 gpm). Ground water is mostly used for stock and domestic purposes. In the Beaverhead River valley, some ground water is used for irrigation.

The ground-water potential of the alluvial deposits along the Big Hole River, a tributary to the Jefferson River, is excellent. The alluvial fill is some 50 m (160 ft) thick with an average saturated thickness of 10 m (30 ft). Most wells tapping the aquifer are small-capacity domestic and stock wells; however, large yields in the 15 to 60 l/s (250 to 1,000 gpm) range are feasible. Similar conditions prevail in the Madison River valley. Here the alluvial aquifer is only tapped by stock and domestic wells, but potential well yields are estimated at 60 l/s (1,000 gpm).

In the Gallatin Valley, an intermontane basin, ground-water resources are largely undeveloped. More than 1,100 wells, ranging in depth from 3 to 30 m (10 to 100 ft), tap the alluvium beneath the valley floor and the alluvial fan deposits chiefly for domestic and stock purposes. Over 40,000 ha (100,000 acres) are irrigated by surface water. Yields of some irrigation wells reach 120 l/s (2,000 gpm). Excessive recharge has caused waterlogging in an area covering some 7,000 ha (17,000 acres). 63)

The Townsend Valley in west-central Montana is underlain by permeable alluvium over 30 m (100 ft) thick. Over 500 wells tap this aquifer, chiefly for stock and domestic use. Irrigation is mostly by surface water, and some 2,800 ha (7,000 acres) are waterlogged. 64)

The Helena Valley, a small intermontane basin northeast of the capital city of Helena, is underlain by alluvial deposits and fine-grained lake sediments. Principal aquifers are thick alluvial fans and permeable beds in the lake deposits. Some 120 wells ranging in depth from 3 to 130 m (10 to 400 ft) tap the aquifers. Most of the wells are for stock and domestic use. Yields range from 10 to 20 l/s (150 to 300 gpm), but yields up to 60 l/s (1,000 gpm) would be possible. A large area of the alluvium in the valley is fully saturated and over 3,200 ha (8,000 acres) are waterlogged. This situation is caused by irrigation on the higher lands of the valley. 65)

In the vicinity of Butte, the principal aquifer is the alluvium in a valley south of the city. The aquifer covers 37 sq km (23 sq mi), is relatively thick, and yields sufficient water for domestic and stock wells. Although most of the water used in the area is from surface-water supplies, the number of domestic wells is increasing. 66)

The Tobacco Plains area in northwestern Montana is underlain by alluvial deposits of over 30 m (100 ft) in thickness. Ground water from sand and gravel zones is used for municipal, domestic, and stock supplies. Potential well yields are estimated between 15 and 60 l/s (250 and 1,000 gpm). The present ground-water use is small, but the area has excellent ground-water potential.

Another area in northwestern Montana with an excellent potential for further ground-water development is Camas Prairie valley. Alluvial deposits are tapped by water wells that yield 12 to 30 l/s (200 to 500 gpm) and range in depth from 3 to 25 m (10 to 75 ft). Pumpage is small and mainly for stock and domestic use. About 120 ha (300 acres) of land are waterlogged.

In the White Sulphur Springs area, permeable alluvial deposits along the Smith River form the principal aquifer. Ground water is chiefly used for stock and domestic use, but there is some irrigation with ground water. Yields of over 60 l/s (1,000 gpm) are reported from wells completed in sand and gravel deposits in buried stream channels. 67)

Alluvial deposits along the lower Sun River, a tributary of the Missouri River at Great Falls, form an excellent aquifer. Yields of existing wells range from 0.3 to 5 l/s (5 to 60 gpm), but potential well capacities are estimated at 15 to 60 l/s (250 to 1,000 gpm).

In eastern Montana, there are fewer areas with extensive and thick unconsolidated aquifers. One of the most important is the buried pre-glacial channel between the Missouri River and the Milk River at Havre and its eastward continuation along the Milk River and the Missouri River. In the lower Marias area the sediments in the channel are some 120 m (400 ft) thick. Aquifers within these channel deposits are little explored but have a high ground-water potential. 68) Over 200 stock and irrigation wells use water from the alluvial aquifer in the Big Sandy-Laredo area.

In Blaine County, the valley fill of the pre-glacial Missouri River has a maximum thickness of about 60 m (200 ft). Alluvial deposits along the Milk River are tapped by a small number of stock and domestic wells. Further eastward, in the Missouri River valley, the alluvium bordering the river reaches a thickness of 40 m (130 ft) in places. Permeable sand and gravel beds yield large quantities of water to over 200 wells. Well depths range from 3 to 60 m (10 to 200 ft), and individual well yields range from one to 40 l/s (15 to 650 gpm). 68) In northern Blaine County, north of the Milk River valley, a large elevated plateau (Big Flat) is covered by glacial till underlain by a thick sand and gravel aquifer of Tertiary age called the Flaxville Formation. This formation, up to 25 m (75 ft) thick, is very productive and yields up to 75 l/s (1,200 gpm) to large-capacity wells. 69)

Alluvial deposits along the Musselshell River in Wheatland, Golden Valley, and Musselshell Counties are tapped by over 100 stock and domestic wells. Thickness of the permeable alluvium is some 7 to 10 m (20 to 30 ft). Some wells yield 30 l/s (500 gpm) but most have a small capacity. 67,70)

Along the Yellowstone River there are several sections where the alluvial deposits are capable of yielding 12 to 60 l/s (200 to 1,000 gpm) to wells. These areas include the section from Park County to Forsyth in Rosebud County, downstream of Miles City, and from Glendive to the North Dakota state line. In the Miles City stretch, some 120 wells ranging in depth from 3 to 30 m (10 to 100 ft) pump water from the alluvium. The water is used chiefly for stock and domestic purposes. Potential yields of 15 l/s (250 gpm) are possible near Miles City. From Terry to Glendive there are over 325 small-capacity wells in the alluvial aquifer. Yields of 15 to 30 l/s (250 to 500 gpm) are obtained near Terry. Waterlogging of irrigated tracts is prevalent in this region. 71,72) The largest ground-water development in the Yellowstone River valley is downstream of Glendive, where more than 300 wells obtain water from the alluvial deposits. The water is used chiefly for stock, domestic, and municipal purposes.

Along Clarks Fork and Rock Creek (tributaries of the Yellowstone River), the alluvial aquifer is widely used for stock and domestic supplies. Some 600 wells yielding from 0.6 to 18 l/s (10 to 300 gpm) pump about 6 million cu m (4,700 acre-ft) of water per year. Some water is used for industrial purposes.

In the lower Bighorn Valley and the Lower Little Bighorn Valley, some 500 wells use water from the alluvium for stock and domestic purposes. Yields of 10 to 20 l/s (several hundred gpm) are possible in some areas. Waterlogging is widespread in both valleys. 73,74)

Bedrock Aquifers -

Many rock formations are water-bearing, but because of complex geologic conditions not all formations are found in any given area. Well depths, aquifer thickness, yield, and water quality vary widely from region to region. Major bedrock aquifers are the Fort Union Formation, the Hell Creek and Fox Hills Formations, the Judith River Formation, the Eagle Formation, the Kootenai Formation, the Madison Formation, the Amsden Formation, the Tensleep Sandstone, and the Chugwater Formation.

The Fort Union Formation consists of beds of sandstone, shale, and coal, and has a known maximum thickness of 670 m (2,200 ft). The formation lies at the surface over vast areas of eastern Montana and in several areas of south-central Montana. Within the outcrop area of the formation, wells 10 to 100 m (30 to 300 ft) deep will encounter adequate supplies of water for stock and domestic use in sandstone beds. Coal beds also yield water. Well yields range up to 4 l/s (60 gpm), with most yields under one l/s or 15 gpm. The shale zones frequently act as confining beds, and flowing wells are present in many areas.

The Hell Creek and Fox Hills Formations contain sandstone aquifers which yield small to medium quantities of water to wells. The combined thickness of the two formations varies from 150 to 400 m (500 to 1,200 ft). On the Cedar Creek anticline in eastern Montana, the two formations form one single aquifer.

The Judith River Formation consists of sandstones, siltstone, shale, and lignite beds with a maximum total thickness of about 120 m (400 ft). Sandstones are the principal water-yielding units within the formation. The Judith River Formation is an important aquifer where it is exposed in north-central Montana. The formation becomes shaly and less productive toward the east. The Parkman Sandstone in Big Horn County and the Two Medicine Formation in Glacier and Toole Counties are stratigraphically equivalent to the Judith River Formation and have similar water-bearing characteristics.

The Eagle Formation, consisting of about 80 m (250 ft) of sandstone, shaly sandstone, and a lower massive sandstone member (Virgelle Sandstone), is an excellent aquifer. Moderately large yields up to 16 l/s (250 gpm) can be obtained from this formation. A few wells flow at rates up to 5 l/s (75 gpm). The formation "shales out" to the east.

The Kootenai Formation (part of Dakota Sandstone aquifer system) consists of 120 to 150 m (400 to 500 ft) of shale and sandstone. A basal sandstone about 30 m (100 ft) thick is an excellent aquifer, as are other sandstone beds in the formation. Most wells tapping the Kootenai yield from 0.3 to 10 l/s (5 to 150 gpm), but flowing wells of 3 to 100 l/s (50 to 1,500 gpm) are reported in Fergus, Garfield, and Big Horn Counties.

The Madison Formation consists of 200 to 500 m (700 to 1,500 ft) of limestone of karstic nature in the upper part. It is a source of a number of large springs in Montana and Wyoming, and oil tests have produced large flows from the formation. The limestone is an excellent aquifer in Carbon County where it lies at a depth of about 300 m (1,000 ft). Potential well yields are over 190 l/s (3,000 gpm). In Cascade County, the Madison is found at shallower depth, and well yields range from 0.3 to 3 l/s (5 to 50 gpm). Much information on the aquifer stems from oil tests that now produce water by artesian flow. Ground water from the Madison Formation is also used for secondary recovery operations in several oil fields. 75) The limestone is a potential source of large amounts of ground water.

The Amsden Formation of late Mississippian and early Pennsylvanian age consists of several hundred feet of sandstone, shale, and cavernous limestone. The aquifer is tapped by wells in the Judith River basin and Big Horn and Carbon Counties.

The Tensleep Sandstone of Pennsylvanian age and the Chugwater Formation of Triassic age both contain aquifers capable of yielding large quantities of water to wells. However, few have been drilled in these formations.

Minor sandstone aquifers are found within the thick shale beds that cover large areas in eastern Montana. The Precambrian crystalline rocks in western Montana are capable of yielding small quantities of water to wells.

Oregon

Oregon is a mountainous state with sharply contrasting climatic and ground-water conditions. The western third of the state is occupied by mountains of the Coast Range, the Cascade Range, and the Klamath Mountains. Between the coastal and the Cascade mountains lies the Willamette Valley, a predominantly flat alluvial area where most of Oregon's population resides. The valley is drained by the Willamette River which flows northward into the Columbia River.

The Coast and Cascade Ranges and the Klamath Mountains receive as much as 2,500 mm (100 in) per year of precipitation, in contrast to the Willamette Valley, which has an average precipitation of 900 mm (35 in) per year. The Cascades are composed of permeable volcanic rocks, so that infiltration of precipitation and resulting recharge to the ground-water reservoir are high. Infiltration is less in the Klamath Mountains and the Coast Range which are composed of less permeable rocks, and most precipitation becomes runoff.

The eastern two-thirds of the state forms part of the Columbia Plateaus and the Basin and Range physiographic provinces. The Columbia Plateaus cover the eastern and north-central portions of the state. They are underlain by volcanics and continental sedimentary rocks. The Basin and Range section in southeastern Oregon is characterized by block faulted mountains and internally drained basins. This region is underlain mainly by volcanic rocks. Precipitation east of the Cascades ranges from 200 to 400 mm (8 to 16 in), except in the Wallowa Mountains in the northeast corner of the state, which receives 750 to over 1,000 mm (30 to over 40 in). Major rivers draining eastern Oregon are the Columbia, Snake, Deschutes, John Day, and Grande Ronde.

Runoff in the state is about 430 mm (17 in), equivalent to some 295 cu hm/d (78 bgd). 7) Most of this high runoff takes place along the steep slopes of the Coast and Cascade Ranges and the Klamath Mountains. By contrast, runoff in most of eastern Oregon is less than 25 mm (one in). Figure 14 shows the major drainage and physiographic features.

Alluvial deposits in the main river valleys and the Columbia River Group basalt are the two principal aquifers. The principal ground-water areas are each discussed below.

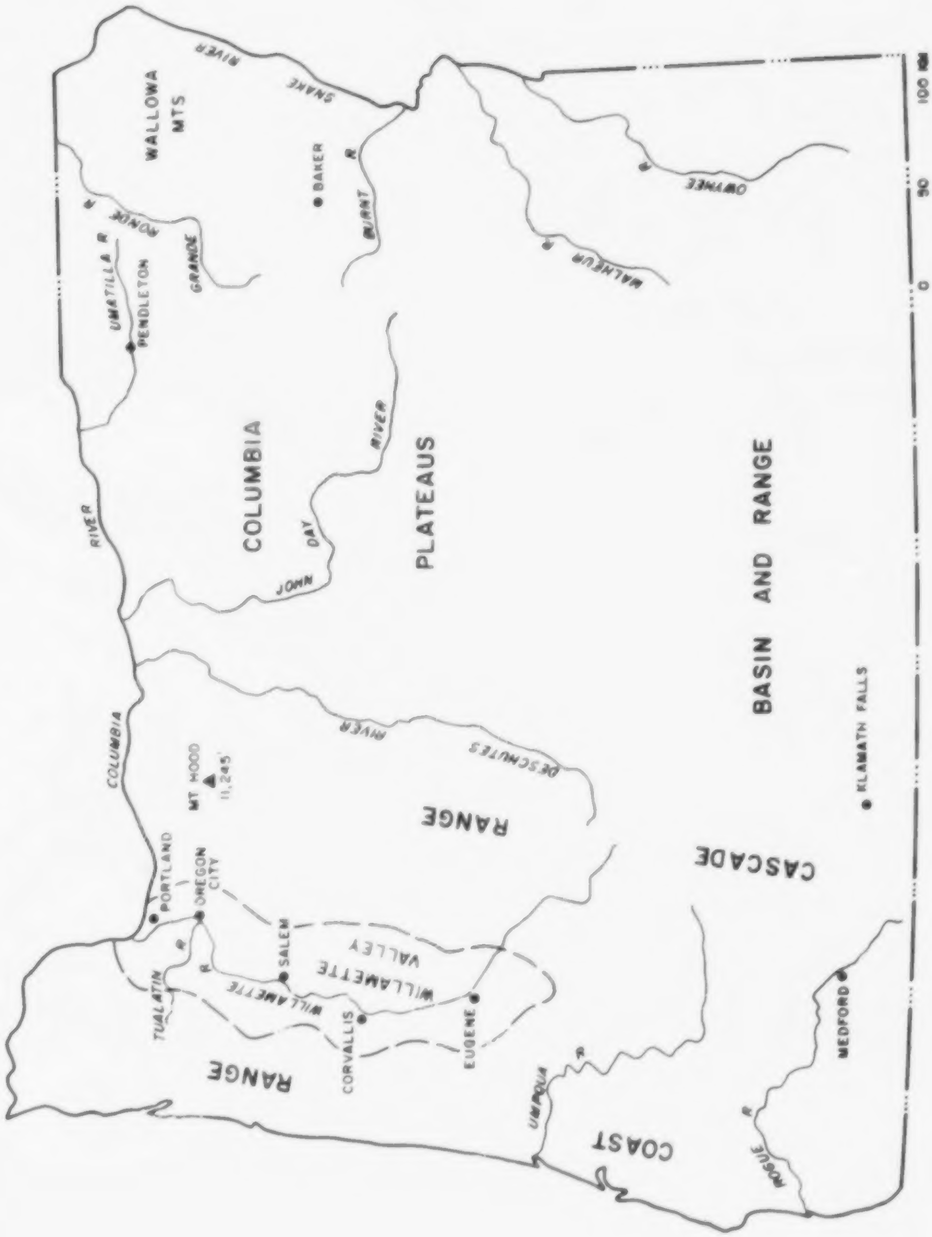

WALLOWA MTS
SNAKE RIVER
BAKER
BURNT R
GRANDE RONDE R
UMATILLA R
PENDLETON
COLUMBIA
PLATEAUS
JOHN DAY RIVER
COLUMBIA RIVER
OWYHEE R
MALHEUR R
BASIN AND RANGE
DESCHUTES RIVER
MT HOOD
11,245'
CASCADE
RANGE
KLAMATH FALLS
PORTLAND
OREGON CITY
SALEM
WILLAMETTE VALLEY
WILLAMETTE R
TUALATIN R
CORVALLIS
EUGENE
COAST
RANGE
UMPQUA R
ROGUE R
MEDFORD
0 50 100 KM
0 25 50 MI

Figure 14. Oregon - Major drainage and physiographic features.

Their locations and the general availability of ground water in the state are shown in Figure 15. Although the use of ground water in the state is still relatively small, increases in irrigation, industrial development, and population will result in a sharp increase in the amount of ground water withdrawn. No serious regional ground-water problems of either quantity or quality exist, although there is concern about liquid waste disposal practices in the lava terrane of eastern Oregon.

Ground-water investigations in the state are carried out by the U. S. Geological Survey and the Oregon State Engineer's office. In recent years, the Water Resources Research Institute at Oregon State University has undertaken some ground-water studies.

Willamette Valley

The Willamette Valley is part of a long, narrow lowland, the Puget-Willamette Trough, which extends northward into the state of Washington. This basin is filled with sedimentary and alluvial deposits flanked by marine sedimentary rocks of the Coast Range and volcanic rocks of the Cascade foothills. These rocks extend beneath the alluvial deposits and appear in places above the valley floor. The bedrock floor is irregular so that the thickness of the alluvial deposits varies from place to place. Ridges of volcanic rock extend across the valley near Salem and Oregon City, dividing the valley into four sections, namely: southern Willamette Valley, northern Willamette Valley, Tualatin Valley, and the Portland Basin. 76)

Aquifers in the southern Willamette Valley are terrace deposits and alluvium underlain by poorly permeable marine and volcanic bedrock. Thickness of the valley-fill deposits ranges from 9 to 40 m (30 to 120 ft). Yields of large-capacity public-supply wells tapping a sand and gravel aquifer in the Eugene-Springfield area range from 15 to 110 l/s (several hundred to 1,700 gpm). 77) In the Corvallis-Albany area, the yields of wells completed in the alluvial aquifer range up to 50 l/s (800 gpm). 78)

In the northern Willamette Valley, the major aquifers are the sand and gravel deposits along the floodplain, and the Troutdale Formation, a thick sequence of mudstone, sandstone, and conglomerate. Much of the valley surface is covered by sandy silt, which is 30 m (100 ft) thick in places. Locally, buried volcanic rocks are good aquifers. In the Molalla-Salem Slope area, the Troutdale Formation is the principal aquifer and yields about 19 l/s (300 gpm) to individual

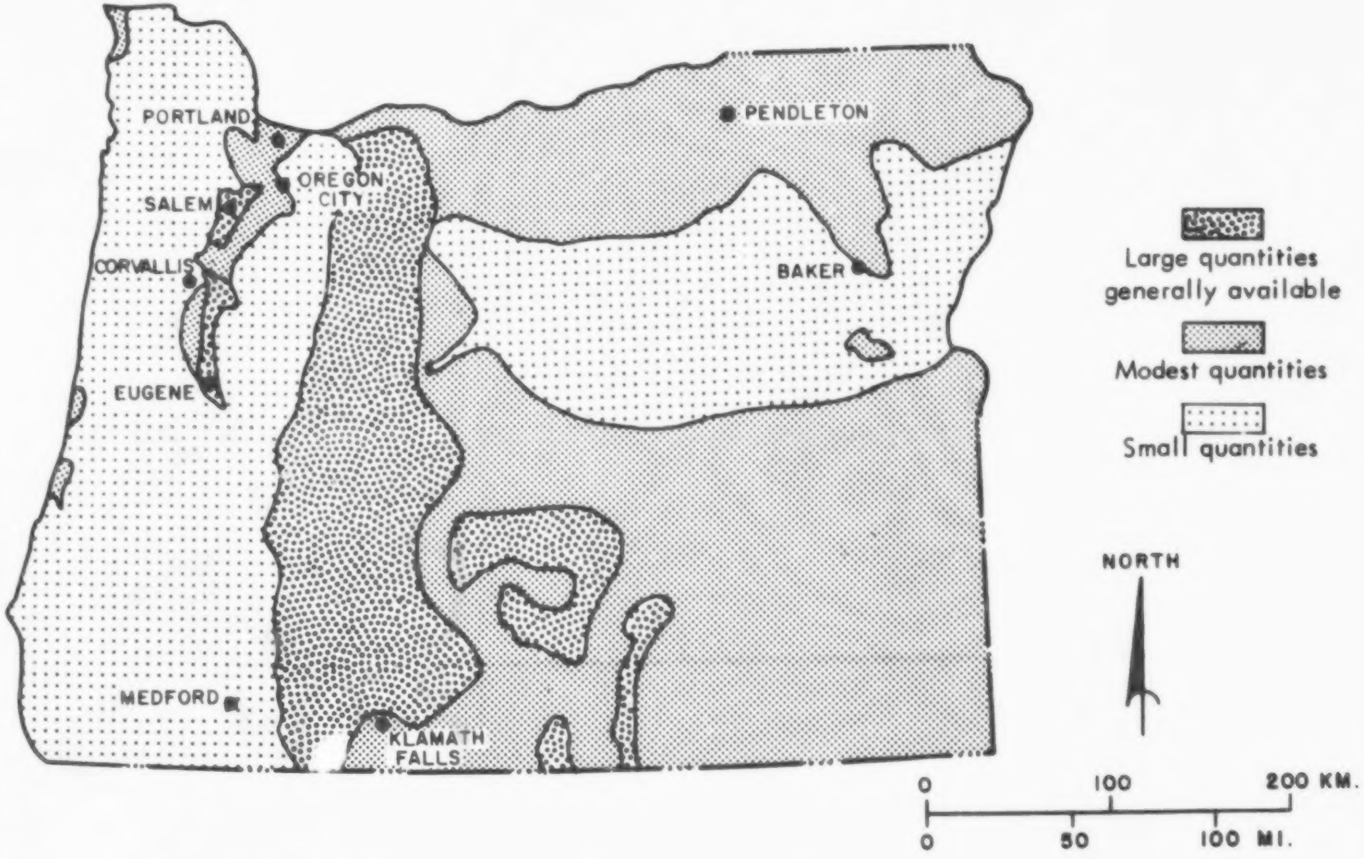

PORTLAND
OREGON CITY
SALEM
CORVALLIS
EUGENE
MEDFORD
KLAMATH FALLS
PENDLETON
BAKER
Large quantities generally available
Modest quantities
Small quantities
NORTH
0
100
200 KM.
0
50
100 MI.

Figure 15. Oregon - Availability of ground water. 128)

wells. Wells tapping the Columbia River Group basalt can yield about 13 l/s (200 gpm) each. 79) In the Eola-Amity Hills area near Salem, most wells tap the Troutdale Formation, which is generally less than 60 m (200 ft) thick. Well yields range up to 32 l/s (500 gpm). 80) Conglomerates of the Troutdale Formation and alluvium along the Willamette River yield as much as 100 l/s (1,600 gpm) to wells in the French Prairie area, north of Salem. Most wells tapping alluvial deposits here are less than 15 m (50 ft) deep; wells in the Troutdale Formation are less than 60 m (200 ft) deep. 81)

Tualatin Valley, a structural basin formed by downwarping of the Columbia River Group, contains valley fill, mainly clay and fine sand but with significant sand and gravel beds. These deposits have a maximum thickness of 460 m (1,500 ft). Sand and gravel lenses in the valley fill and basalt form the principal aquifers. Thousands of wells, most of which are of small capacity, tap these aquifers. The population in the valley is increasing rapidly due to its proximity to metropolitan Portland. 82)

Within the Portland area, ground water is obtained mainly from the Troutdale Formation, fluvio-lacustrine deposits of Pleistocene age, and alluvium of Recent age. Locally, the Columbia River basalt and the Boring lava yield substantial amounts of water. Overpumping has led to lowered water levels in the west-side business district of Portland. 83,84)

Medford-Ashland Area -

Sand and gravel beds deposited by the Rogue River and its tributaries constitute the most productive aquifer in the Medford area in southwestern Oregon. A maximum yield of 6 l/s (100 gpm) is possible from some wells. Moderate to deep wells in the region tap the non-marine sedimentary rocks and volcanic deposits. 85) In the Ashland area, along the California state line, alluvial deposits are too thin to develop for water supplies without the possibility of inducing pollution from the surface, and most wells tap sandstone, shale, tuff, and conglomerate beds. Yields to wells are in the range of 0.3 to one l/s (5 to 15 gpm), sufficient for domestic needs. 86)

Coastal Belt -

Terrace deposits and alluvial sands containing fresh water are present where rivers flowing out of the Coast Range meet the Pacific Ocean. Dune and beach sands are present along some coastal sections and are most prominent near the mouth of the Columbia River (Clatsop dunelands), near the town of Florence, and near Coos Bay. Yields of 13 to 19 l/s (200 to 300 gpm) are common in the Coos Bay area where the sand deposits are 3 km (2 mi) wide, and have a maximum thickness of about 60 m (200 ft). Recharge to these sand deposits is high, over 1,400 mm (55 in) per year, and large ground-water supplies can be developed without causing sea-water contamination. The sands are virtually the only natural significant reservoirs of fresh water along the coast as the older rocks are relatively impermeable. 87,88)

Cascade Range -

The Cascade mountains are formed of permeable volcanic rocks and readily absorb water from rain and snow. The mountain range acts as an important recharge area to rivers and aquifers in both the Willamette Valley to the west and the Deschutes River basin to the east.

Northeastern Oregon -

This area forms part of the Columbia Plateau, a region underlain by basaltic rocks covering more than 130,000 sq km (50,000 sq mi) in Washington, Oregon, and Idaho. The thickness of the basalt is 150 to 300 m (500 to 1,000 ft) at the edge and 1,200 to 1,500 m (4,000 to 5,000 ft) in the central part of the tri-state region. The rock unit consists largely of layered basalt flows, each 3 to 60 m (10 to 200 ft) in thickness, with some interbedded sedimentary material. Permeable zones, openings, and fractures in the basalt give it a high transmissivity, and yields of over 60 l/s (1,000 gpm) are possible in such areas. 89) Ground-water discharge from the basalt is through numerous springs. There are several intermontane basins, such as Baker Valley, Burnt River valley, Grande Ronde Valley, and the Umatilla River basin, where ground-water development has taken place.

In Baker Valley, the major aquifers are alluvium and terrace deposits that yield moderate to large quantities of water to wells. 90) Fluvioglacial deposits in the Burnt River valley are over 300 m (1,000 ft) thick. Well yields are less than 3 l/s (50 gpm), except for areas where wells tap gravel lenses. Basaltic rocks in this valley yield as much as 60 l/s (1,000 gpm) to wells. 91)

In the Grande Ronde Valley, valley-fill deposits are as thick as 600 m (2,000 ft). Most of the wells obtain small to moderate supplies of water from water-table aquifers in the valley fill and alluvial fan deposits. Moderate to large supplies of water are obtained from artesian aquifers in the fan alluvium and the Columbia River basalt. 92)

The Umatilla River basin, in which the city of Pendleton and the town of Hermiston are located, is underlain by alluvial deposits and basalt of the Columbia River Group. The basalt is the more productive aquifer, capable of yielding 60 l/s (1,000 gpm) to wells. 93) The ground water forms tabular bodies confined within scoriaceous zones of the basalt. Potentiometric-head relations are varied and complex due to structural complications and compartmentation of the hydraulic system. 94) Sand and gravel beds in the alluvium locally yield as much as 125 l/s (2,000 gpm) to irrigation wells, but generally yields are much lower.

Southeastern Plateaus -

The region of Oregon receiving the least precipitation and recharge is underlain mostly by volcanic rocks of moderate permeability. Principal aquifers are alluvial sand and gravel beds in the basin areas and lava flows and pyroclastic rocks that overlie impermeable bedrock. Excessive pumpage of ground water has caused progressive declines of the water level in some areas. 95)

Washington

The water resources of the state of Washington are very large. The two principal mountain ranges in the western portion of the state - the Cascades and the Olympics - intercept moisture flowing in from the Pacific and cause heavy precipitation and runoff to occur. Annual precipitation is as much as 5,000 mm (200 in) in the Olympic peninsula and averages about 1,800 mm (70 in) in western Washington. By contrast, the annual precipitation in eastern Washington is about 500 mm (20 in) per year, and is as little as 130 mm (5 in) in local arid sections. 71) The annual runoff across the state varies widely. It is 2,000 mm (80 in) or more in the coast ranges, 1,000 mm (40 in) in the Cascade Range, and 10 mm (0.5 in) or less in the Columbia Plateaus region. Total runoff is about 325 cu hm/d (86 bgd). 96) Principal rivers are the Columbia and its tributaries, the Snake, Spokane, Pend Oreille and Okanogan. The Columbia River basin is one of the most extensively developed river basins in the country. More than two-thirds of the population lives in the Puget Trough lowland which is a center of commerce and industry.

In spite of the large total water supply, problems exist due to uneven distribution of runoff. In the arid eastern zone traversed by the Columbia River, the stream bed is far below the plateaus, and surface water is not easily utilized. Problems related to ground-water mining are beginning to occur in heavily pumped areas. In the western portion of the state, the runoff takes place largely during the winter and flows directly into Puget Sound and the ocean. These factors cause complex water-management problems. Water-demand projections for the next 30 years indicate no rapid rise in irrigation development but a substantial increase in domestic and industrial water demand. 96)

The most important aquifers are the unconsolidated or semiconsolidated deposits of Quaternary age and the basaltic volcanic rocks present in the Columbia Plateau, along with principal ground-water provinces (Figure 16). 97,98) Ranges in well yields are shown on Figure 17. Ground-water supplies about 12 percent of the state's water needs. In 1970, total ground-water pumpage was some 3.2 cu hm/d (840 mgd). About 1.1 cu hm/d (290 mgd) of this was used for public supply.

Ground-water investigations in Washington have been conducted by the U. S. Geological Survey and the Washington State Department of Water Resources (now part of the Department of Ecology). In recent years, the State of Washington Water Research Center in Pullman has studied ground-water problems and interstate aquifers. 99)

Coast Range Peninsula -

The Coast Range Peninsula zone extends from the Olympic peninsula in the north to the Columbia River in the south. The mountain region is underlain by fine-grained sedimentary rocks that yield little water to wells. Unconsolidated glaciofluvial deposits of sand and gravel along the shoreline and major streams are the principal aquifers.

Significant ground-water development has taken place in the Sequim-Dungeness area on the Strait of Juan de Fuca in Clallam County, the coastal zone of Grays Harbor and Pacific Counties, and the Chehalis River valley. In the Sequim-Dungeness area, extensive glacial outwash deposits yield large quantities of water to wells, and irrigation with ground water is widespread. Wells in this region are less than 60 m (200 ft) deep and commonly yield more than 13 l/s (200 gpm). 100) Along the coast north and south of Grays Harbor, terrace deposits yield moderate amounts of water to wells and springs. Development of ground-water supplies is limited to North Beach Peninsula, Tokeland-Westport, and the area between Point Brown and Moclips. Most of the ground water is used for domestic purposes, but moderately large quantities are used for irrigation and frost control of

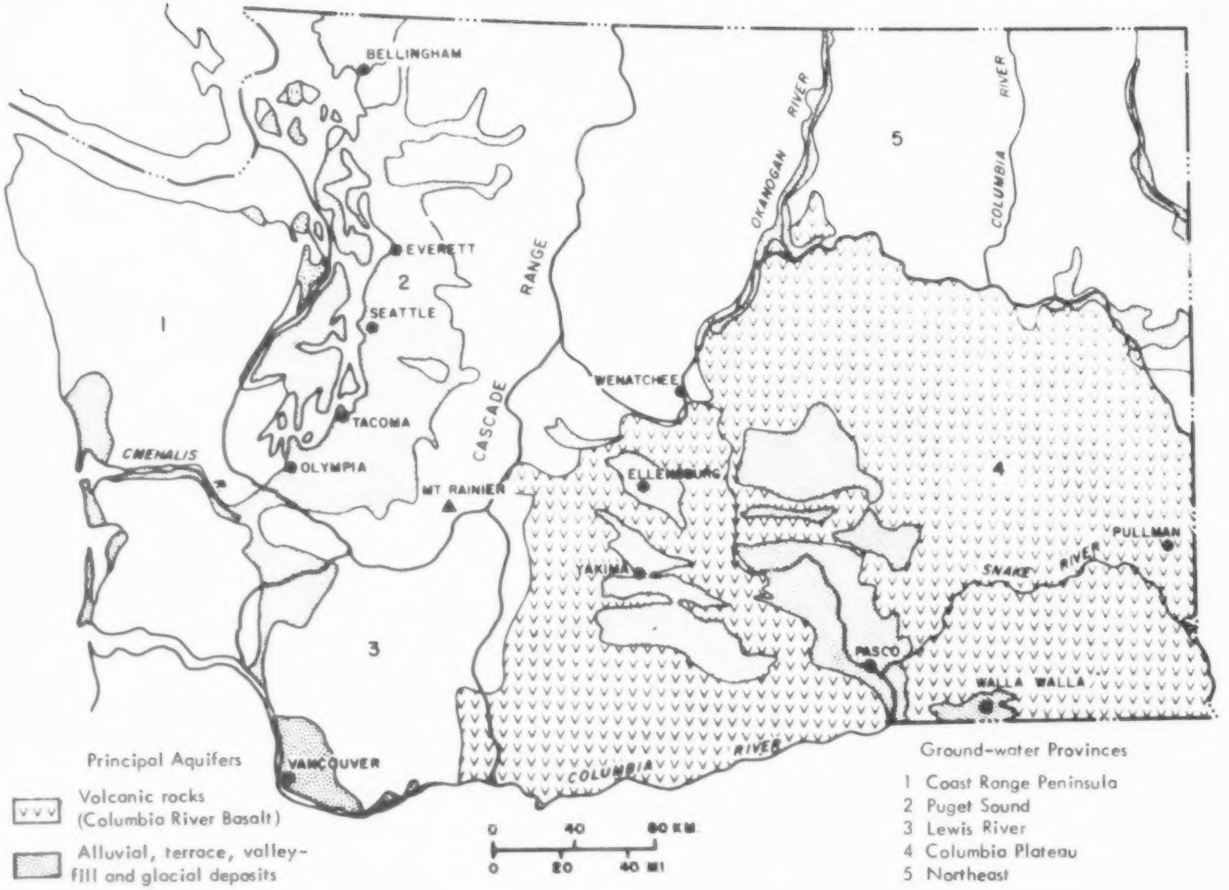

BELLINGHAM
EVERETT
SEATTLE
TACOMA
OLYMPIA
MT RAINIER
CASCADE RANGE
WENATCHEE
ELLENSBURG
YAKIMA
PASCO
WALLA WALLA
PULLMAN
VANCOUVER
CHEHALIS
OKANOGAN RIVER
COLUMBIA RIVER
SNAKE RIVER
1
2
3
4
5
Principal Aquifers
Volcanic rocks (Columbia River Basalt)
Alluvial, terrace, valley-fill and glacial deposits
0
40
80 KM
0
20
40 MI
Ground-water Provinces
1 Coast Range Peninsula
2 Puget Sound
3 Lewis River
4 Columbia Plateau
5 Northeast

Figure 16. Washington - Ground-water provinces and major aquifers.[89,97]

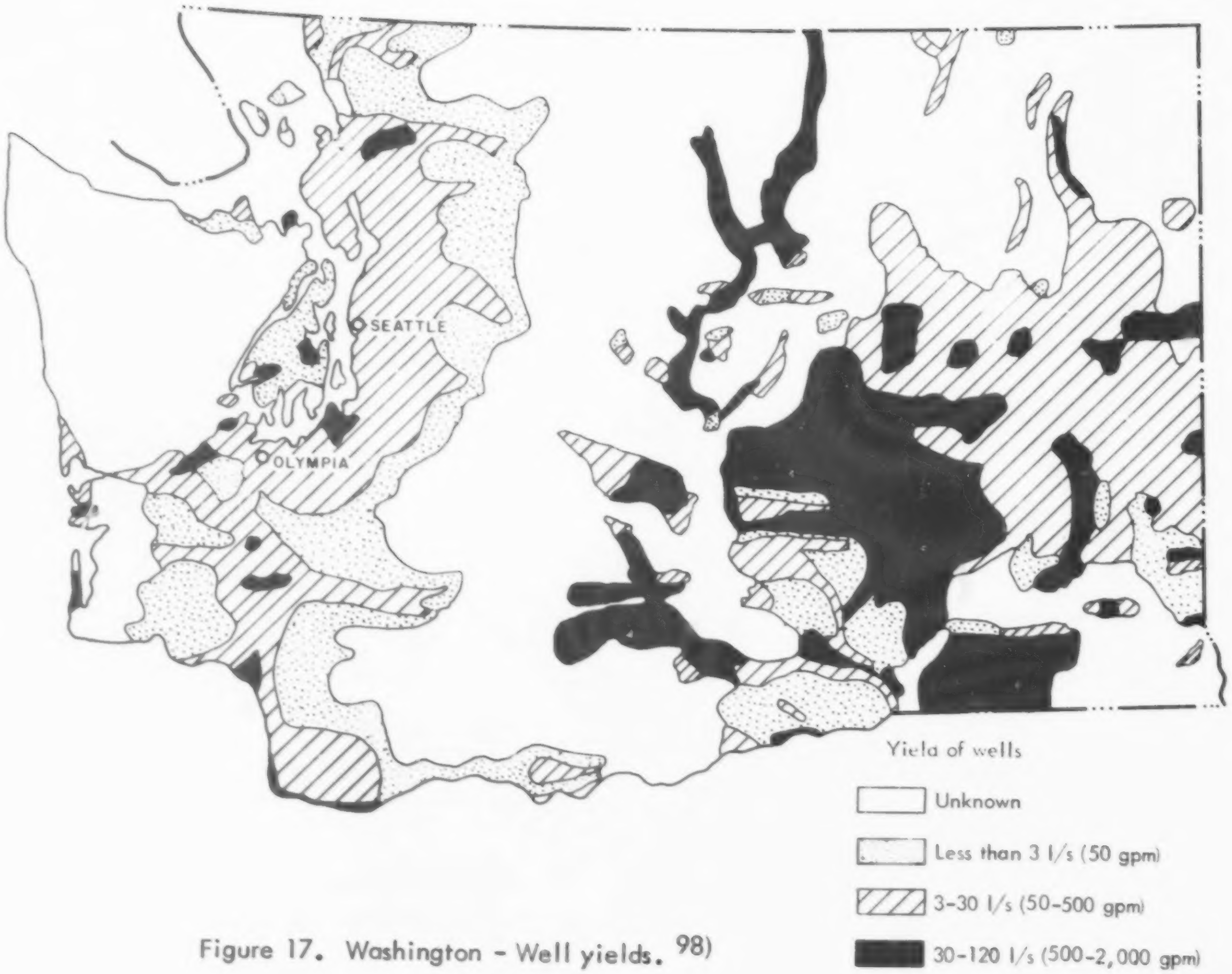

SEATTLE
OLYMPIA
Yield of wells
☐ Unknown
▒ Less than 3 l/s (50 gpm)
▨ 3-30 l/s (50-500 gpm)
■ 30-120 l/s (500-2,000 gpm)

Figure 17. Washington - Well yields. 98)

cranberry bogs. [101]

In the Chehalis River valley, wells obtain water from two distinct alluvial aquifers. An upper aquifer extends to a depth of 30 m (100 ft), with a deeper water-bearing zone present below it. Well yields range from 13 to 190 l/s (200 to 3,000 gpm). Ground-water use is mostly for domestic supplies. Increased withdrawal of ground water for industrial and irrigation supplies is anticipated as the region is rapidly being developed. [102]

Puget Sound -

The Puget Sound province is an extensive lowland area bounded by the Coast Ranges on the west and the Cascade Range on the east. Much of the lowland is underlain by glacial and alluvial deposits with a combined thickness of over 600 m (2,000 ft) in places. Permeable sand and gravel beds form the principal aquifers and are widely tapped for public supplies, industrial, irrigation, and domestic use. Most of the population and industry in the state resides in this lowland. Ground water is used to supply the city of Olympia and, in part, the city of Tacoma.

Recharge to the aquifer systems is excellent due to heavy precipitation and runoff from the flanking mountain systems. From a regional point of view, only a very small percentage of this ground-water recharge is being withdrawn, and much larger use of the ground-water resources in the lowland is possible. Yields of large-capacity wells are often greater than 60 l/s (1,000 gpm). Flowing artesian wells are common, with rates as high as 125 l/s (2,000 gpm).

In the Tacoma area (Pierce County), 35 public-supply systems use wells to supply water to some 300,000 people. The most productive Quaternary aquifers are in the Salmon Springs Drift, the Vashon deposits, and alluvium. Yields of wells are excellent. Tacoma public-supply wells yield from 50 to 570 l/s (800 to 9,000 gpm).

In the Puyallup River valley, coarse sand and gravel present from 25 to 45 m (80 to 150 ft) below land surface constitute the principal aquifer. Yields of wells range up to 150 l/s (2,400 gpm) and average 18 l/s (285 gpm). [103]

In the Olympia area, ground water is found in abundant quantities in glacial deposits. Outwash aquifers are over 90 m (300 ft) thick in places, and the yield of public supply and industrial wells averages over 13 l/s (200 gpm). Aquifers underlying the alluvium of the Deschutes floodplain are used for industrial supplies in Tumwater. Some 3,400 wells in this region (Thurston County) withdrew about 12.3 million cu m (10,000 acre-ft) of water in 1964, about half of which was used for irrigation. 104)

In the area between Tacoma and Seattle (southwestern King County), about 50 percent of the population was supplied by ground water in 1964. About 44.3 cu hm (11,700 million gallons) of ground water was withdrawn during 1962. The main aquifers are coarse sand and gravel in outwash and alluvial fan deposits. Along Puget Sound, well yields of 6 to 30 l/s (100 to 500 gpm) are common, but further inland, in the river valleys (White, Green and Cedar Rivers), yields greater than 95 l/s (1,500 gpm) are possible. 105)

In the Seattle region (northwestern King County), ground-water withdrawals are relatively small. The Seattle water system obtains its water from the Cedar River. Few industries use ground water, due in part, to the location of industrial plants along Elliott Bay and the Duwamish River, where ground-water supplies are difficult to obtain. Ground water is used principally for domestic and small municipal water systems, with an estimated 3,000 domestic wells pumping small quantities of ground water. The principal aquifers in the Seattle region are sand and gravel beds in the Vashon stratified drift. Yields of wells range from 0.3 to 32 l/s (5 to 500 gpm). 106)

North of Seattle, ground-water development has taken place in the coastal areas of Skagit and Whatcom Counties. Ground water accounts for some 30 percent of the total quantity of irrigation water used. 7)

The islands in Puget Sound are entirely dependent on ground water because streams are small and intermittent. Wells on Whidbey and Camano Islands (Island County) supply about 3.8 million cu m (one billion gallons) of water per year. All ground water is obtained from sand and gravel beds within glacial and interglacial deposits. Individual water-bearing zones range in thickness from 3 to 8 m (10 to 25 ft). Well yields range from 1.2 to 5 l/s (20 to 80 gpm). 107)

Lewis River Province -

The Lewis River province includes the southern portion of the Puget Trough. Principal aquifers are the alluvial deposits in the Columbia River floodplain and the sand and gravel beds of Pleistocene and Recent age along the Cowlitz River and on the lowlands east and north of the city of Vancouver. These unconsolidated rocks are underlain by

Tertiary and older volcanic and sedimentary rocks. Nearly all public water-supply systems use ground water. Ground-water use in 1960 totaled about 4,400 l/s (100 mgd), 80 percent of which was used by industry. 7) Yields of many industrial and municipal wells in the Vancouver area are over 125 l/s (2,000 gpm).

Columbia Plateau -

The Columbia Plateau, covering two-fifths of the state, is divided by mountain ridges and entrenched river channels. It is underlain by a series of horizontal basaltic lava rocks consisting of numerous flows with a composite thickness of over 3,000 m (10,000 ft) in the Hanford area. A relatively thin layer of loess, glacial drift, and other sedimentary material overlies much of the plateau. The basalt rocks form one of the nation's most important ground-water reservoirs. Ground water in the basalt is found in permeable zones such as fractures, shrinkage openings, joints, and interbedded unconsolidated materials. Water-bearing zones exhibit marked differences in thickness, permeability, and areal extent. In some places, sufficient volumes of ground water can only be obtained from wells 150 to 300 m (500 to 1,000 ft) deep. Perched and artesian ground-water conditions prevail in many areas.

In the Yakima River valley and its tributaries, alluvial and glacial deposits are over 150 m (500 ft) thick. Although surface water is used for large irrigation projects, ground water is the source of most public water systems. Infiltration from streams and irrigation return flow has filled the aquifers below the valley, and there is a problem of waterlogging in the Kittitas Valley. 96) The mountainous western portion of the Yakima River basin is underlain by volcanic rocks of low porosity and permeability, and yields little or no water to wells.

The Hanford Reservation of the U. S. Atomic Energy Commission, located along the Columbia River north of Richland, is underlain by glaciofluvial outwash sands and gravels to a maximum depth of 52 m (170 ft). Below these deposits is the Ringold Formation, an extensive lacustrine and fluviatile deposit of sand, silt, gravel, and clay, with an average thickness of 90 m (300 ft) but locally reaching 180 m (600 ft). Below these sediments is a series of basalt rocks with a thickness of at least 3,000 m (10,000 ft). 108) Ground water occurs under artesian conditions in the basalt rocks and under water-table conditions in the unconsolidated deposits. Ground-water discharge is to the Columbia River. 109)

Over 1,300 wells have been constructed on the Hanford project area. Some were originally constructed to supply water for sanitary facilities; others to observe the movement and quality of ground water in the vicinity of waste disposal facilities, and still others to obtain geologic data. About 200 to 300 observation and monitoring wells are presently in use. 110)

East of the Columbia River lies the Columbia Basin Irrigation Project area, covering some 200,000 ha (500,000 acres). This area has been irrigated with surface water since 1952. Ground-water levels have risen substantially - as much as 75 m (250 ft) - as a result of irrigation, and available ground-water reserves have increased greatly. Waterlogging is becoming a serious problem in some places. 96) Outside the Project area, ground water is the chief source of irrigation, municipal, and domestic supplies.

In the Ritzville-Odessa area, a rapid increase in ground-water withdrawal for irrigation has resulted in a water-level decline of 15 to 25 m (50 to 90 ft), prompting the state's water management agency to close a large part of the area to further appropriation. 111) Pumpage from 100 irrigation wells in 1965 was some 27 million cu m (22,000 acre-ft). Well depths range from 60 to 210 m (200 to 700 ft), and yields of individual wells range from 15 to 125 l/s (a few hundred to over 2,000 gpm). 112) In the Walla Walla Basin, ground water is found in gravel beds located within a thick clay bed and in the underlying basalt. Pumpage in 1969 was 62 million cu m (50,000 acre-ft), produced equally from the older gravel aquifer and the basalt. Of this total, about 14 million cu m (11,000 acre-ft) was pumped in the Oregon part of the basin. 96) Overdraft occurs locally, but the basin-wide situation shows an annual excess of recharge over pumpage. 113)

In southeastern Washington (Whitman County), all public supplies are obtained from ground-water sources. Basalt is the principal aquifer, and the yield of large-diameter wells in this formation is about 8 to 13 l/s (125 to 200 gpm) for every 30 m (100 ft) of saturated basalt penetrated. Wells in the Pullman region, the principal area of ground-water use, tap an artesian zone in the basalt at about 46 to 52 m (150 to 170 ft) below the valley floor. Yields of tens of l/s (several hundred gpm) are also obtained from wells that penetrate sand and gravel in the Snake River valley. 114)

The average ground-water pumpage in the Pullman area was about 3 cu hm (800 million gallons) in 1967. Locally, water levels in some wells have declined 11 m (35 ft) in the 1935-

1965 period. 96) Because of concern for falling water levels, applications for additional diversion of artesian ground water in the Pullman area were curtailed by the Washington Division of Water Resources in 1953.

Northeast -

This mountainous region includes the Columbia River drainage basin upstream of the Spokane River, the Okanogan River basin, Chelan County, a portion of the Pend Oreille River basin, and the Spokane Valley. The bedrock consists mostly of intrusive igneous rocks and some sedimentary, metamorphic, and volcanic rocks. Except for some water-bearing zones in volcanic rocks, most of the bedrock yields little water to wells. Principal aquifers are sands and gravels in river valleys and intermontane basins. In the Spokane Valley, permeable outwash deposits fill deep buried valleys and constitute a prolific aquifer. Ground water moves through these outwash deposits toward Spokane from an extensive recharge zone (Rathdrum Prairie) across the border in Idaho. Yields of more than 300 l/s (5,000 gpm) are obtained from large-diameter wells penetrating these gravel zones. 115)

Recharge to the Spokane Valley aquifer is estimated at more than 860 million cu m (700,000 acre-ft) per year. Ground-water pumpage totaled about 185 million cu m (150,000 acre-ft) in 1973. The city of Spokane, the largest single user of ground water, obtains its water from ten well fields that pump about 74 million cu m (60,000 acre-ft) annually. An additional 33 million cu m (27,000 acre-ft) annually is pumped for municipal, domestic, and industrial supplies in the suburban area around the city. 116)

Elsewhere in the region, ground water is used for practically all domestic and municipal water-supply systems. Irrigation water is obtained from surface sources. Ground-water development is largest in the valleys of the tributaries of the Columbia River, especially the Okanogan and Wenatchee.

Wyoming

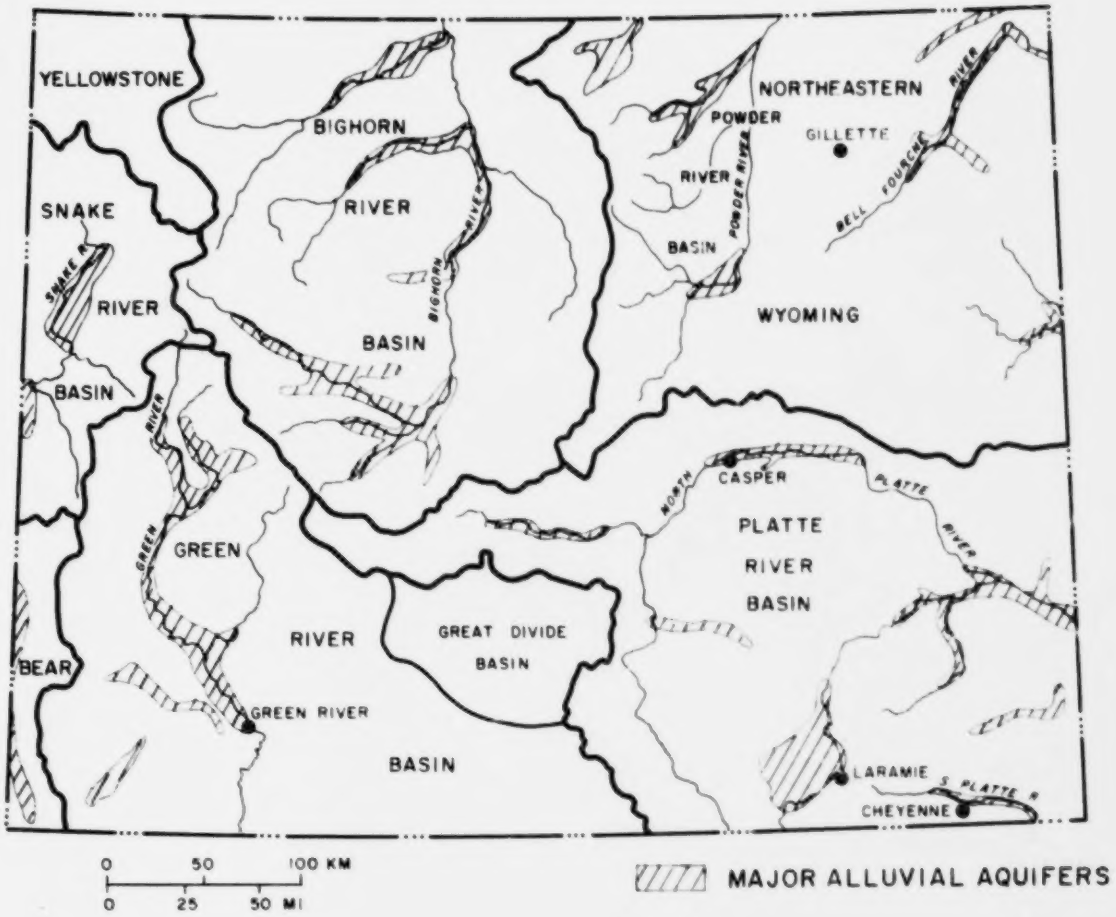
Wyoming straddles the Continental Divide and contains the headwaters of four major rivers in the United States. The Green and Little Snake Rivers in southwestern Wyoming are the headwaters of the Colorado River, and the Bear River along the western boundary of Wyoming forms the headwaters of the Great Salt Lake basin. The Snake River in Jackson Hole flows westward into Idaho where it joins the Columbia River. The rivers in the remaining 72 percent of the state form the headwaters of the Missouri River. Important rivers belonging to the Missouri River drainage system are the Yellowstone, Bighorn, Powder, and North Platte. In south-central Wyoming, the Continental Divide splits to encircle a closed drainage basin, the Great Divide Basin.

Precipitation varies from 150 to 200 mm (6 to 8 in) per year in the desert portions of the Colorado and Missouri River basins, to over 750 mm (30 in) in the Continental Divide area. The eastern plains receive about 230 to 400 mm (9 to 16 in) of precipitation per year. The average annual runoff is about 75 mm (3 in), equivalent to some 19.5 billion cu m (15.8 million acre-ft) of water. An additional 1.9 billion cu m (1.5 million acre-ft) flows into Wyoming from other states. Wyoming's present consumptive use of surface water is only about 3.2 billion cu m (2.6 million acre-ft) per year. About 70 percent of the runoff occurs during spring and early summer, leaving little water for the rest of the year.

Present users (1973) consume only 15 percent of the state's surface-water resources. The other 85 percent flows into other states. Under interstate compacts and court decrees, Wyoming may have an additional 22 percent of the resource over the present water allocation. By far the largest consumptive use of water is for irrigation which depletes about 2.65 billion cu m (2.15 million acre-ft) of surface water and 165 million cu m (133,500 acre-ft) of ground water per year on 690,000 ha (1.7 million acres) of land. Ground water also supplies 39.6 million cu m (32,100 acre-ft) per year for municipal, domestic, and stock use and 62 million cu m (50,400 acre-ft) per year for industrial use. Including irrigation, the present use of ground water in the state totals some 266 million cu m (216,000 acre-ft) per year, which is equivalent to 8 percent of all water consumed in the state. 117) Principal aquifers in the state are the alluvium, terrace deposits, Tertiary sandstones, and Paleozoic limestones.

Significant increases in ground-water use are anticipated in the Bighorn River basin (irrigation and industry), northeastern Wyoming (industry), Platte River basin (irrigation), Green River basin and Great Divide Basin (industry), and the Snake River basin (municipal and domestic). Figure 18 shows the major drainage basins and distribution of the principal alluvial aquifers. Major consolidated aquifers are shown on Figure 19. Table 7 lists the various aquifers, ranges in depth, yields of wells, and total dissolved solids content.

The alluvial aquifers are shallow and thus relatively inexpensive to develop. The gross volume of ground water in storage in the alluvial aquifers is estimated at 12.3 bil-


YELLOWSTONE
SNAKE RIVER BASIN
SNAKE R.
BIGHORN RIVER BASIN
BIGHORN RIVER
NORTHEASTERN WYOMING
POWDER RIVER BASIN
POWDER RIVER
GILLETTE
BELL FOURCHE RIVER
BEAR
GREEN RIVER BASIN
GREEN RIVER
GREAT DIVIDE BASIN
PLATTE RIVER BASIN
NORTH PLATTE RIVER
CASPER
LARAMIE
CHEYENNE
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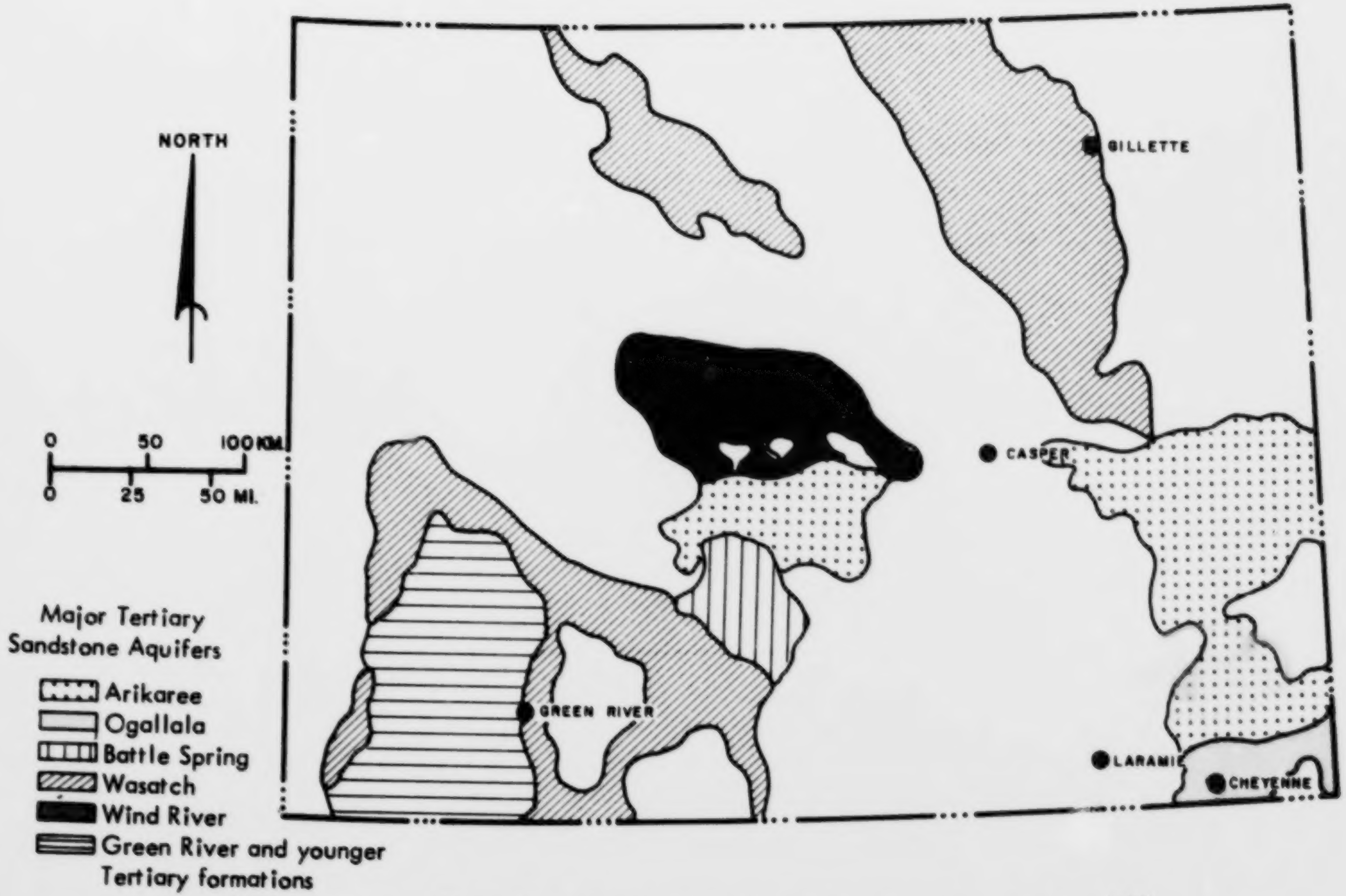
MAJOR ALLUVIAL AQUIFERS

Figure 18. Wyoming - Major drainage features and alluvial aquifers. 117)


NORTH
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GILLETTE
CASPER
GREEN RIVER
LARAMIE
CHEYENNE
Major Tertiary
Sandstone Aquifers
Arikaree
Ogallala
Battle Spring
Wasatch
Wind River
Green River and younger
Tertiary formations

Figure 19. Wyoming - Major Tertiary sandstone aquifers.117)

Table 7. WYOMING. WELL DEPTH, YIELD AND WATER QUALITY OF AQUIFERS. (17)

Geologic period	Aquifer/formation	Drainage basin or area	Depth range of wells in meters	Anticipated well yield in l/s Common range	Anticipated well yield in l/s High range	Total Dissolved Solids reported range in mg/l
Quaternary	Sand and gravel (unconsolidated)	Green River Basin	3 - 30	0.6 - 6	25 - 38	250 - 2,800
		Platte River Basin	3 - 90	1.6 - 19	63 - 190	234 - 786
		Northeastern Wyoming	3 - 30	0.3 - 16	19 - 38	106 - 3,340
		Bighorn River Basin	3 - 30	0.6 - 29	38 - 130	256 - 4,600
		Snake River Basin	3 - 30+	1.3 - 16	32 - 95+	20 - 600
		Bear River Basin	3 - 56	1.3 - 19	57 - 130	285 - 1,770
Tertiary	Ogallala (Ss)	Platte River Basin	46 - 210	3 - 10	50 - 110	175 - 336
	North Park (Ss)	Green River Basin	9 - 30	0.3 - 6	16 - 25	196 - 237
		Platte River Basin	30 - 46	2.5 - 22	82 (Spring)	242 - 820
	Browns Park (Ss)	Green River Basin	4.6 - 60+	19		205
		Platte River Basin	60 - 91+	1.6	63	176 - 831
	Bishop (Cg)	Green River Basin	37±	2.5	6.3	558
	Pass Creek (Cg)	Green River Basin	11 - 43	1.6	13	200 - 380
	Arikaree (Ss)	Platte River Basin	15 - 180	9.5 - 50	63 - 69	232 - 468
	White River (St)	Platte River Basin	30 - 180	3.2 - 19	57 - 130	216 - 713
	Bridger (Ss)	Green River Basin	9 - 300+	0.3 - 1.6	3.2	563 - 4,910
	Green River (Ss)	Green River Basin	6 - 370+	0.06 - 4.7	13	500 - 7,000
	Wasatch (Ss)	Green River Basin	30 - 910	0.6 - 6.3	19 - 44	200 - 3,700
		Northeastern Wyoming	12 - 300	0.06 - 2.5	6.3 - 38	160 - 6,620
		Bighorn River Basin	9 - 60	0.06 - 1.3	3.2 - 7.6	621 - 1,880
	Battle Spring (Ss)	Green River Basin	9 - 300	0.06 - 6.3	19 - 63	200 - 1,000
	Wind River (Ss)	Platte River Basin	23 - 170	0.06 - 0.9	6.3 - 19	NA
		Bighorn River Basin	6 - 300	0.06 - 3.2	6.3 - 38	247 - 5,000
	Fort Union (Ss)	Green River Basin	46 - 110	0.06 - 6.3	32	827 - 3,320
		Northeastern Wyoming	46 - 180	0.06 - 1.9	6.3	484 - 3,250
		Bighorn River Basin	15 - 150	0.06 - 1.9	7.6	1,000

Note:

Ss	- Sandstone	Ls	- Limestone
Sh	- Shale	Dol	- Dolomite
St	- Siltstone	Cg	- Conglomerate

* in oil test waters

Table 7 (continued). WYOMING. WELL DEPTH, YIELD AND WATER QUALITY OF AQUIFERS.117)

Geologic period	Aquifer/formation	Drainage basin or area	Depth range of wells in meters	Anticipated well yield in l/s Common range	High range	Total Dissolved Solids reported range in mg/l
Cretaceous	Lance (Ss)	Green River Basin	39 - 300+	0.3 - 1.9	19	1,600
		Platte River Basin	210±	0.6	6.3	416 - 1,250
		Northeastern Wyoming	46 - 370+	0.06 - 3.2	32	450 - 3,060
		Bighorn River Basin	15 - 60	0.06 - 0.6	1.9	NA
	Fox Hills (Ss)	Northeastern Wyoming	60 - 700	1.3 - 4.4	13 - 32	1,240 - 3,290
	Almond (Ss)	Green River Basin	30 - 370	1.3	6.3	500 - 1,500
	Erickson (Ss)	Green River Basin	18 - 370	0.6 - 4.7	6.3 - 13	300 - 1,500
	Rock Springs (Ss)	Green River Basin	27 - 300	0.13 - 6.3	13 - 50	600 - 6,000
	Mesaverde (Ss)	Green River Basin	880±	0.3 - 2.5	6.3	1,170 - 5,300
		Northeastern Wyoming	12 - 910	1 - 2.5	38 - 4.4	550 - 1,360; to 34,793*
	Cody (Ss)	Northeastern Wyoming	30 - 340+	0.06 - 0.3	6.3 - 13	6,392 - 12,580
		Bighorn River Basin	15 - 120	0.06 - 0.3	0.6 - 2	1,750 - 6,240
	Frontier (Ss)	Platte River Basin	18 - 240	0.06 - 0.3	0.6	862 - 3,030
		Northeastern Wyoming	21 - 610	0.06 - 0.3	6.3 - 19	390 - 2,360; to 25,000*
		Bighorn River Basin	14 - 120	0.06 - 0.3	0.6	1,800 - 2,350; to 13,071*
	Cloverly or Inyan Kara or Lakota or Dakota (Ss)	Green River Basin	300±	1.6	6.3	223 - 557; 3,000 to 36,000*
		Platte River Basin	30 - 1,070	0.3 - 4.7	7.9 - 16	278 - 1,770
		Northeastern Wyoming	76 - 1,800	1.6 - 6.3	13 - 57	218 - 1,820; to 18,706*
		Bighorn River Basin	300 - 1,500+	1.6 - 3.2	9.5 - 22	1,905 - 14,825*
Jurassic	Sundance (Ss)	Green River Basin	1,220±	0.06 - 0.3	2	1,100 as high as 50,000 in oil test water
		Northeastern Wyoming	120 - 210	0.06 - 0.3	1.6	894 - 2,310
	Nugget (Ss)	Green River Basin	1,220±	3.2	13	9,000
Triassic	Spearfish (Ss)	Northeastern Wyoming	6 - 270+	0.06 - 2	6.3 - 13	2,590
	Chugwater (Ss)	Platte River Basin	9 - 60	0.3 - 3.8	13 - 19	1,000 - 2,040
		Bighorn River Basin	12 - 370+	0.06 - 1	6.3 - 13	3,040 - 43,032*

Table 7 (continued). WYOMING. WELL DEPTH, YIELD AND WATER QUALITY OF AQUIFERS. 117)

Geologic period	Aquifer/formation	Drainage basin or area	Depth range of wells in meters	Anticipated well yield in l/s Common range	Anticipated well yield in l/s High range	Total Dissolved Solids reported range in mg/l
Permian	Satanka (Ss)	Platte River Basin	27 - 110	2	38	NA
	Embar-Phosphoria (Ls/Dol)	Bighorn River Basin	76 - 180+	0.6	9.4 - 44	1,078 - 44,355*
Pennsylvanian	Tensleep/Amsden (Ss/Ls), or Casper (Ss), or Minnelusa (Ss/Ls/Dol)	Green River Basin	200±	13		339 (spring) - 1,650
		Platte River Basin	120 - 240	3.2 - 11	63	226 - 274 and 440 (spring)
		Northeastern Wyoming	73 - 1,980	1.6 - 16	32 - 130	255 - 3,620; to 200,000*
		Bighorn River Basin	12 - 910	0.6 - 13	32 - 63	168 - 560; 646-5,640*
Mississippian	Madison or Pahasapa (Ls)	Green River Basin	200±	13		1,650
		Northeastern Wyoming	150 - 2,300	6.3 - 160	440 - 590	290 - 3,290
		Bighorn River Basin	270 - 910	3.2 - 47	63 - 160	168 - 560; 728 - 3,902*
Devonian	Jefferson (Dol)	Bighorn River Basin	1,770±	NA	NA	3,276*
Silurian	-	-	-	-	-	-
Ordovician	Bighorn (Dol)	Northeastern Wyoming	0 - 60+	63 (spring)		427 - 3,219*
		Bighorn River Basin	610 - 1,220	19 - 44		166; 408 - 2,895*
Cambrian	Cambrian (Ss)	Green River Basin	126±	6.3 - 9.5		214 - 663
		Northeastern Wyoming	20 - 1,800	13		124; 18,634*
		Bighorn River Basin	720 - 1,950	130 - 205		136 - 440; 1,869-4,137*
Precambrian	Granite	Platte River Basin	Recharge areas	0.6 - 1		252 (spring)
		Northeastern Wyoming		0.6 - 1		63 (spring)

lion cu m (10 million acre-ft), and recharge to the aquifers from precipitation is estimated at 1.2 billion cu m (one million acre-ft) per year.

The Tertiary sandstones cover extensive areas in the state and are of interest to the rural population and for stock supplies. Most wells drilled into sandstones yield small quantities of water, but large yields are encountered in some areas. The depths of such sandstone wells commonly range between 90 and 300 m (300 and 1,000 ft).

Paleozoic sedimentary rocks form excellent artesian aquifers. Cavernous limestones and permeable sandstones of Pennsylvanian to Cambrian age yield artesian flows of more than 100 l/s (1,600 gpm). Many such wells have been drilled by the petroleum industry. Sandstones and shales of Cretaceous through Permian age commonly yield 0.7 to 6 l/s (11 to 100 gpm) to wells. Regional aquifers best suited for large-scale development are the Arikaree sandstone and the Madison through Flathead interval.

Since 1954, ground-water studies in the state have been carried out by the U. S. Geological Survey in cooperation with the Wyoming State Engineer. Ground-water conditions in each of the major drainage basins is briefly discussed below.

Green River Basin -

Ground water in most of the basin is virtually untapped. The principal use of ground water is for stock and domestic purposes. Ground-water pumpage for industrial use (oil well drilling, secondary recovery processes, coal mining and trona processing) is some 172 l/s (4 mgd). Some 530 ha (1,300 acres) are irrigated by ground water. 118)

The shallow, unconsolidated, water-table aquifers are alluvial, windblown and glacial deposits of Quaternary age. Many of the consolidated Tertiary formations also appear to have an upper zone of unconfined water that may extend to depths of over 50 m (several hundred ft). The Green River, Wasatch, Fort Union and older formations which underlie most of the basin contain water under artesian conditions. The depth to water is generally less than 60 m (200 ft), but the artesian aquifers in the deeper part of the basin lie at depths exceeding 300 m (1,000 ft). Well yields range from 0.6 to 6 l/s (10 to 100 gpm). Yields greater than 30 l/s (500 gpm) could probably be obtained from wells 600 to 1,500 m (2,000 to 5,000 ft) deep, penetrating sandstone aquifers of the Wasatch and Fort Union Formations and from wells in the alluvial aquifer near Pinedale and east of Boulder. 119)

The eastern part of the basin, including the Great Divide Basin, is underlain by many sandstone aquifers of different distribution, thickness, and permeability. Single widespread aquifers with uniform characteristics are not present. Ground water is generally under artesian pressure. Large quantities of ground water can probably be obtained from the Madison Limestone, sandstones of Pennsylvania, Jurassic, Cretaceous and Tertiary age, and alluvial deposits. 120)

Bear River Basin -

Alluvial sands and gravels in the valley of the Bear River form the principal aquifer. Well yields range from 6 to 80 l/s (100 to 1,300 gpm).

Snake River Basin -

Ground water is available in floodplain alluvium and valley fill along the major streams, in glacial outwash deposits, and in Tertiary bedrock formations. In Jackson Hole, sand and gravel beds are tapped by wells yielding from 0.6 to 60 l/s (10 to 1,000 gpm). In the Teton Valley, ground water from alluvium is used for domestic, stock, and irrigation supplies. In the Salt River valley, alluvial deposits are over 60 m (200 ft) thick; ground water from this aquifer is used for irrigation. Total consumptive use of ground water was about 2.6 million cu m (2,100 acre-ft) in 1970. 121,122)

Yellowstone River Basin -

Almost the entire area lies within Yellowstone National Park. Ground water obtained from alluvial deposits supplies part of the domestic and campsite water needs. Small to moderate yields of 2 to 19 l/s (30 to 300 gpm) and, in some places (for example, in the valley of Clarks Fork), large yields of over 60 l/s (1,000 gpm) can be obtained from valley-fill deposits that commonly are 30 m (100 ft) thick.

Bighorn River Basin -

The Bighorn River basin includes the Wind River basin and covers about 50,000 sq km (20,000 sq mi) in north-central Wyoming. Principal aquifers are the sand and gravel beds on the floodplains and terraces. Yields from these aquifers range from 0.6 to 125 l/s (10 to 2,000 gpm). Much of the recharge to alluvial aquifers and terrace gravels is irrigation return flow. Ground water is also available from Tertiary and older rocks, but because of their considerable depth below land surface these aquifers have been little developed. Hundreds of wells tap Tertiary sandstones, such as the Arikaree, Wind River and Fort Union Formations. Well yields are generally in the range of 0.3 to 7.6 l/s (5 to 120 gpm). Higher yields could be obtained by drilling deeper into the saturated section.

Cretaceous sandstones, for example the Lance, Mesaverde, Cody and Frontier Formations, yield 0.3 to 19 l/s (5 to 300 gpm). The Cloverly Formation of Cretaceous age together with pre-Cretaceous formations, yield water along the flanks of the mountains. Ground water in these formations is under confined conditions, and wells flow when first developed. Yields of 30 l/s (500 gpm) and over are reported from the Tensleep, Amsden, Madison, Bighorn and Flathead Formations. Some wells tapping the Madison Limestone yield from 30 to 160 l/s (500 to 2,500 gpm).

The largest user of ground water in the basin, some 62 million cu m (50,000 acre-ft) per year, is the petroleum industry. Some 40 million cu m (33,000 acre-ft) of this ground water is used for waterflooding oil fields by means of injection wells. Pumpage for irrigation was about 27 million cu m (22,000 acre-ft) in 1970. Domestic and stock use of ground water consumes some 315 l/s (5,000 acre-ft/yr). Industrial use of ground water is expected to increase sharply as a result of additional water required by the uranium industry in the Wind River basin. 123,124)

Northeastern Wyoming -

This semi-arid and very water-deficient area includes the Powder River basin and the drainage system of the Belle Fourche and Cheyenne Rivers. As the streams are mostly intermittent, ground water is the principal source of water for drinking, irrigation, stock, and industrial supplies.

Alluvial deposits present in the main river valleys are capable of yielding moderate to large supplies. However, most wells tap the Tertiary sandstones which are present over 70 percent of the area. Yields of wells in sandstone are generally small, mostly less than 3 l/s (50 gpm), and the quality of the water is poor. High yields of up to 38 l/s (600 gpm) are possible in some areas from wells drilled to 300 m (1,000 ft) into Tertiary and Cretaceous aquifers.

Pre-Cretaceous formations, including sandstone and limestone of the Minnelusa/Tensleep interval and limestone of the Pahasapa/Madison interval, may yield up to 570 l/s (9,000 gpm) from depths to 3,000 m (10,000 ft). Near the Big Horn Mountains, industrial wells flow at rates of over 100 l/s (1,600 gpm) from the Tensleep Sandstone and Madison Limestone, encountered at depths of 600 to 2,400 m (2,000 to 8,000 ft). Near the South Dakota state line, the Madison is known to flow at least 60 l/s (1,000 gpm) from a depth of 300 m (1,000 ft) in municipal water wells.[117,125]

Most stock wells are drilled to about 300 m (1,000 ft) to encounter artesian aquifers that flow at land surface, thus eliminating the need for pumping equipment. The uncontrolled flow from artesian wells is a significant portion of the total ground-water diversion in many areas.

Platte River Basin -

The principal aquifers in the Platte River basin are floodplain alluvium, valley-fill and terrace gravels, Tertiary sandstones, and pre-Tertiary sandstone, limestone, and shale. The unconsolidated aquifers are found along the North Platte River and its tributaries, along the Niobrara River, Horse Creek, Lodgepole Creek, and Crow Creek, and within the Laramie basin. Among the major Tertiary aquifers are the Arikaree Sandstone in the western and eastern portion of the basin and the Ogallala Formation in the southeast corner.

Irrigation wells tapping thick alluvial deposits along the North Platte River in Goshen County yield between 60 to 190 l/s (1,000 to 3,000 gpm). Terrace gravels in the Wheatland area form excellent aquifers capable of yielding 6 to 30 l/s (100 to 500 gpm) to wells. In the Carpenter-Egbert-Pine Bluffs area, similar gravel aquifers yield up to 95 l/s (1,500 gpm) to wells.

The Ogallala Formation is tapped by municipal wells of the city of Cheyenne. This aquifer generally yields 3 to 9 l/s (50 to 150 gpm) to wells, but much larger yields are also reported. The Arikaree Formation yields moderate to high supplies of ground water. In the Sweetwater River area, well yields of 50 to 70 l/s (800 to 1,100 gpm) are reported. Similar yields are reported from wells tapping the aquifer in the High Plains region. Locally, the Battle Spring and the Brule and Chadron Formations of the White River Group are important aquifers.

Pre-Tertiary formations in the High Plains area, although highly exploited in Colorado, are little developed here because ground water is available at shallower depth. In the Laramie basin, however, these aquifers are present directly below the floodplain alluvium, and many wells produce water from these rocks. In other areas, the pre-Tertiary aquifers have excellent potential, but the great depth is a deterrent to development.

Ground water in the Platte River basin is used extensively for irrigation, municipal, domestic, stock, and industrial use. The total consumptive use of ground water in 1970 was 152 million cu m (123,000 acre-ft) per year, equal to 60 percent of all ground water withdrawn in the state. About 90 percent of this ground water was used for irrigation. About 1,000 irrigation wells supply water to some 28,000 ha (70,000 acres). Another 28,000 ha (70,000 acres) are irrigated partially by ground water. 126)

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SECTION V

NATURAL GROUND-WATER QUALITY

INTRODUCTION

The natural quality of ground water varies widely from region to region, in accordance with geologic and climatic conditions. The mineral composition of the rocks in the earth's crust and the length of time water is in contact with these rocks determines, to a large degree, the quality of ground water. The combination of volcanism and great structural deformation in the Northwest is responsible for the presence of natural ground water of unusually high temperatures, often highly mineralized. Evaporite deposits of salt and gypsum are present over large areas, often interbedded with other sedimentary rocks. Ground water moving through these formations readily dissolves minerals and carries them in solution to the eventual discharge point.

In arid zones, where recharge is limited, ground-water movement is very slow. The water is in contact with minerals in the surrounding rocks longer and becomes more highly mineralized. High evapotranspiration rates can cause ground water to rise to the land surface and to deposit its mineral load below or at the land surface. All these factors are responsible for serious ground-water quality problems in the Northwest. The states with the most problems are Colorado, Montana, and Wyoming. Relatively few natural ground-water problems exist in Idaho and the Pacific Coast states of Oregon and Washington.

PRINCIPAL PROBLEMS OF NATURAL GROUND-WATER QUALITY

Principal problems of ground-water quality in the Northwest are, in order of importance:

1. Total dissolved solids
2. Iron and manganese
3. Fluoride
4. Trace metals
5. Radionuclides
6. Arsenic
7. Thermal springs

Each of these major ground-water quality problems is discussed below followed by a description of natural ground-water quality on a state-by-state basis. Evaluation of the relative quality of ground water is according to limits for drinking water recommended by the U. S. Public Health Service. 1)

Total Dissolved Solids

The U. S. Public Health Service has a recommended limit on dissolved solids content of 500 mg/l for potable water. However, in water-short areas, people may become accustomed to higher concentrations and use water for drinking that contains 1,000 mg/l or more dissolved solids. A concentration exceeding 2,000 mg/l makes the water unsuitable for domestic use.

Mapping by the U. S. Geological Survey has indicated that more than half of the areas of the states of Colorado, Montana, and Wyoming are underlain by aquifers known to produce water containing at least 1,000 mg/l of dissolved solids. 2) As shown on Figure 20, in most of these regions, the saline ground water is found at depths shallower than 150 m (500 ft). The concentration of total dissolved solids in the shallowest ground water is shown on Figure 21. In northeastern Colorado and isolated areas of Montana and Wyoming, concentrations of dissolved solids in shallow ground water range between 1,000 and 10,000 mg/l. In the Rocky Mountains in Colorado and on some areas of the Colorado Plateau in western Colorado, the shallow ground water contains more than 35,000 mg/l of dissolved solids. Only a few areas in Oregon, Washington, and Idaho are underlain by saline ground water.

In southwestern Colorado, salt anticlines that originated along faults and formed during the deposition of evaporites, have salt cores measurable in hundreds of cu km. 3) Collapse and subsequent erosion have exposed these evaporites to weathering and solution, and the ground water in this region is typically highly saline. Salt seeps and springs in western Colorado add over 450,000 metric tons (500,000 tons) of salt per year to the Colorado River and its tributaries (see discussion on thermal springs). Similar salt springs exist in the Green River basin of Wyoming, producing some 9,100 metric tons (10,000 tons) of salt per year. 4) Connate salt water, often under sufficient pressure to flow at land surface, is present in most areas of the region. The existence of this mineralized water has become known through oil and gas exploratory wells and in some cases from deep water wells. Saline ground water is a frequent by-product of oil and gas production and is either disposed of at the land surface or injected under pressure into the oil or gas reservoir. Highly saline connate water is also encountered in most wells drilled through Columbia River basalt flows in

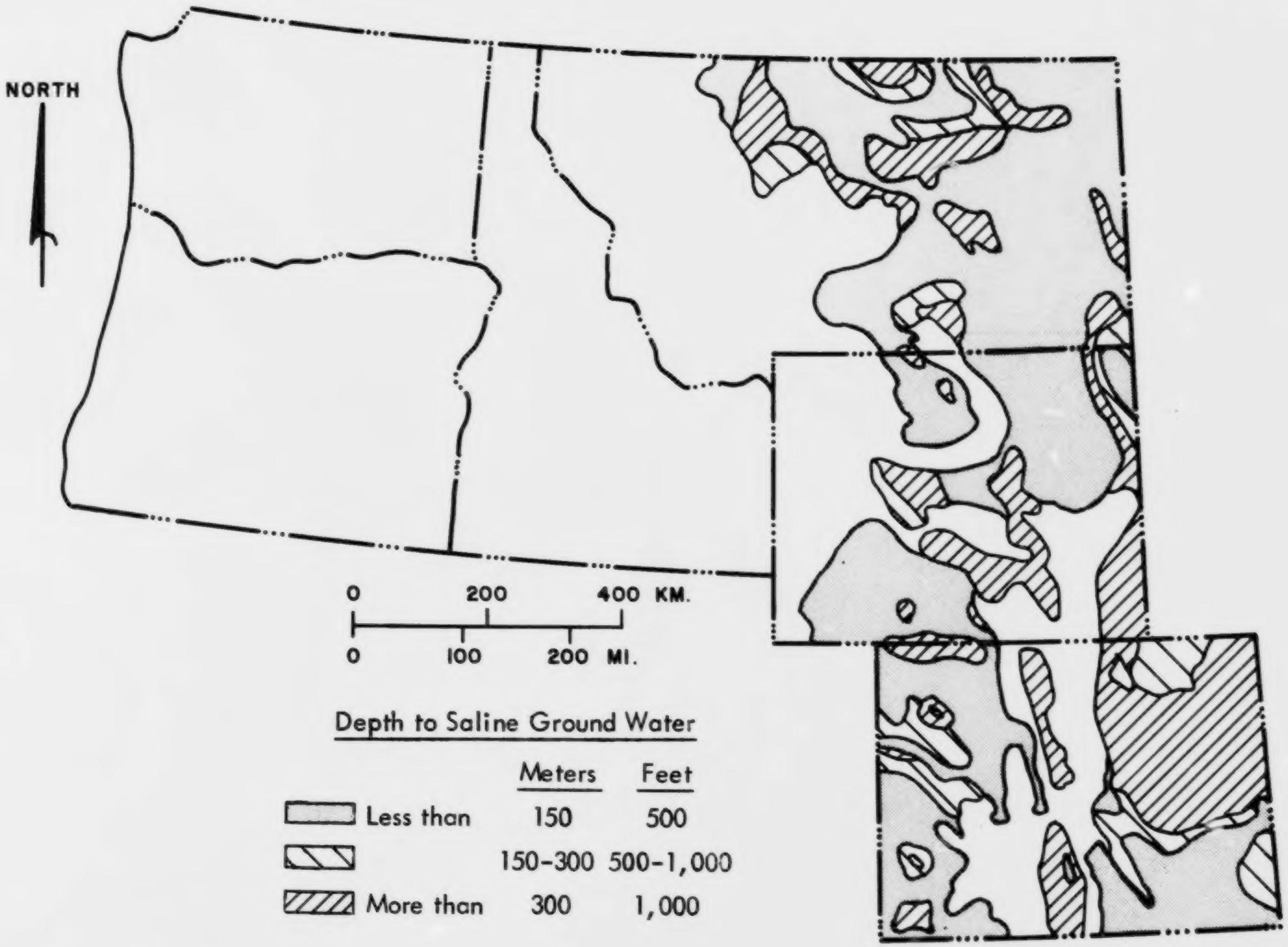
NORTH
0
200
400 KM.
0
100
200 MI.
Depth to Saline Ground Water
Meters
Feet
Less than
150
500
150-300
500-1,000
More than
300
1,000

Figure 20. Depth to ground water containing more than 1,000 mg/l dissolved solids. 2)

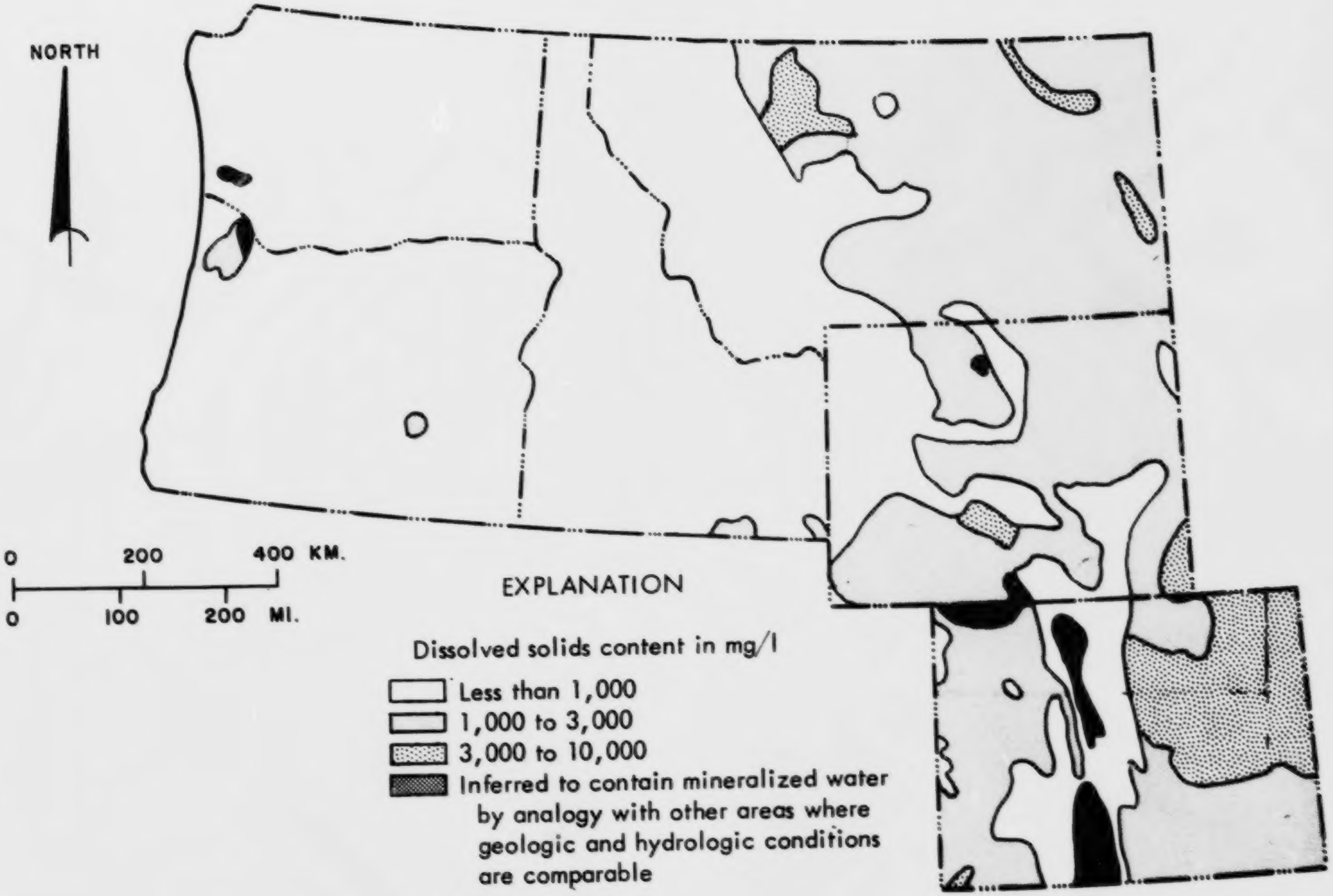
NORTH
0
200
400 KM.
0
100
200 MI.
EXPLANATION
Dissolved solids content in mg/l
☐ Less than 1,000
☐ 1,000 to 3,000
▨ 3,000 to 10,000
■ Inferred to contain mineralized water by analogy with other areas where geologic and hydrologic conditions are comparable

Figure 21. Quality of shallowest mineralized ground water in the Northwest. 2)

Washington and Oregon. 5,6,7)

A summary of 149 representative chemical analyses of shallow saline ground water in the six states is given in Table 8. A regional variation in chemical composition is noticeable from individual analyses. In the Rocky Mountains region, sodium sulfate and sodium chloride waters predominate. Sodium bicarbonate water is prevalent in eastern Montana. All ground water containing 20,000 mg/l or more of dissolved solids is of the sodium chloride type.

The widespread occurrence of saline and hard ground water beneath the Great Plains in Montana, Wyoming, and Colorado is limiting the development of the region and causes a great amount of economic damage. As shown on Figure 22, the hardest ground water occurs in the Plains states. 8) Many towns tap surface-water supplies for drinking water, but the quality of surface water, except for the large rivers, is generally poor, especially in low-flow periods when river discharge is entirely supplied by ground-water discharge. The ground water is only suitable for stock watering and irrigation of well-drained soils. Many towns in eastern Colorado and eastern Montana are forced to resort to expensive demineralization to lower the mineral content to acceptable levels for drinking water. Other communities import or haul water over large distances. Tens of thousands of domestic households use water treatment devices to lower the mineral content of water.

In Montana, a review of records of municipal water quality in 173 communities, practically all supplied by wells, shows that about half of the communities distribute drinking water that exceeds U. S. Public Health Service standards for total dissolved solids and sulfate. Excessive hardness, reaching 1,000 to 1,500 mg/l, is the principal water-quality problem. 9) In Colorado, a study of 91 community water-supply systems, each serving a population in excess of 500 and almost all supplied by ground water, indicates that more than 112,000 people in 25 communities receive water with over 500 mg/l of dissolved solids; 13 communities serving 62,000 people serve water with a dissolved solids content of 1,000 mg/l or more; 49 municipal systems serve hard water (in excess of 120 mg/l). High sulfates are a common problem. 10)

Similar problems exist in Wyoming. The median total dissolved solids content of shallow ground water in that state is about 500 mg/l, rising to over 2,000 mg/l in deeper aquifers. 4) A recent evaluation of the Wyoming public water-supply program showed that of 76 municipal supplies tested, 45 percent exceeded the U. S. Public Health Service recom-

Table 8. TABULATION OF SELECTED CHEMICAL ANALYSES OF SHALLOW SALINE GROUND WATER IN THE NORTHWEST. 2) Constituents in mg/l (milligrams per liter).

	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
State	N	R	M	N	R	M	N	R	M
Colorado	17	1,230 - 8,900	2,310	36	4.0 - 10,100	114	34	8 - 3,910	634
Idaho	10	1,120 - 8,095	1,890 a)	11	15 - 2,780	731	9	324 - 1,340	949
Montana	41	1,081 - 9,207	1,960 a)	46	0.5 - 5,000	72	33	4 - 1,270	70
Oregon	11	1,130 - 8,450	3,580	16	39 - 5,010	908	17	5 - 5,400	800
Washington	4	1,060 - 2,100	-	9	50 - 5,330	1,050	8	182 - 1,500	470
Wyoming	18	1,100 - 6,620	2,220	28	7.0 - 3,475	38	25	3 - 3,310	384

N - Number of samples
R - Common range
M - Median

a) - Calculated

Table 8 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF SHALLOW SALINE GROUND WATER IN THE NORTHWEST. 2) Constituents in mg/l (milligrams per liter).

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)			Sulfate (SO_4)		
State	N	R	M	N	R	M	N	R	M	N	R	M
Colorado	36	15 - 5,580	396	16	0.0 - 3.2	0.10	36	13 - 6,690	512	37	3.3 - 5,870	826
Idaho	11	168 - 1,970	281	6	0.10 - 1.5	-	11	40 - 2,806	284	11	12 - 3,045	153
Montana	45	20 - 2,480	533	32	0.0 - 7.0	0.18	46	2.5 - 3,993	486	46	0.0 - 5,050	486
Oregon	17	5 - 2,550	307	13	0.0 - 2.9	0.12	16	173 - 3,900	854	17	1.1 - 5,020	111
Washington	8	26 - 1,880	118	5	0.05 - 9.5	-	6	73 - 4,260	-	6	0.7 - 468	-
Wyoming	28	64 - 1,430	352	15	0.03 - 25	0.72	28	14 - 2,927	460	28	52 - 4,080	1,000

	Nitrate (NO_3)			Fluoride (F)			pH		
State	N	R	M	N	R	M	N	R	M
Colorado	32	0.0 - 29	2.9	28	0.4 - 10	1.4	34	4.0 - 9.1	7.5
Idaho	9	0.0 - 30	1.5	2	0.2 - 1.7	-	3	6.1 - 8.1	-
Montana	27	0.0 - 35	1.1	27	0.4 - 5.5	1.7	26	7.2 - 9.5	8.0
Oregon	11	0.0 - 17	0.9	10	0.0 - 3.4	0.4	12	6.5 - 8.5	7.2
Washington	5	0.0 - 37	-	3	0.1 - 1.4	-	7	6.6 - 7.7	7.5
Wyoming	22	0.0 - 15	0.8	22	0.0 - 4.2	0.6	25	6.8 - 9.0	7.6

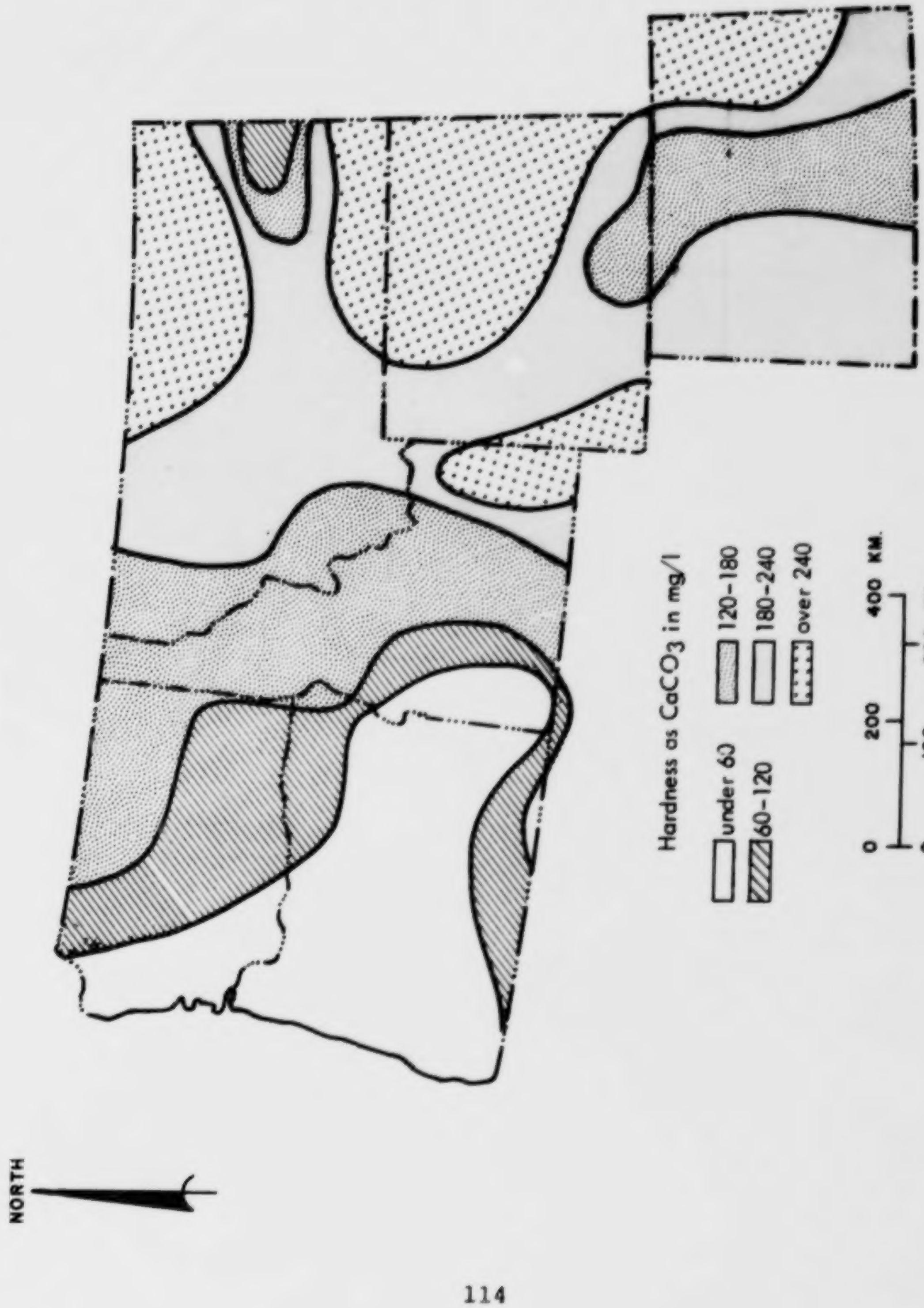
NORTH
Hardness as $CaCO_3$ in mg/l
under 60
60-120
120-180
180-240
over 240
0 200 400 KM.
0 100 200 MI.

Figure 22. Hardness of ground water in the Northwest. 8)

mended limits for total dissolved solids and sulfate. 11) Feasibility studies regarding development of water for industrial supplies in the northeastern part of that state indicate that none of the ground water available for eventual use in coal-conversion plants meets the quality required for boiler-feed water, process water, or cooling water, and demineralization will have to be employed. 12)

The high hardness and high concentration of total dissolved solids in ground water causes considerable economic damage to household appliances and plumbing. In Colorado and Washington, the total household damages caused by treated ground water supplied by public water systems and water from private wells is over ten million dollars per year in each state (Table 9). In all six states, such damages from mineralized ground water are estimated to total some 38 million dollars per year. Per capita household damage of private water well systems ranges from a high of $36 per year in Colorado to less than $6 in Oregon and Washington. Better quality ground water in Oregon and Washington is reflected in lower economic damages. 13)

Iron and Manganese

Next to dissolved solids in severity is the occurrence of iron and manganese in ground waters of the Northwest. The presence of these constituents is caused by the leaching of soluble iron and manganese salts from the rocks and sediments. U. S. Public Health Service limits for iron and manganese in drinking water are 0.3 mg/l and 0.05 mg/l, respectively. 1) Manganese frequently accompanies iron in ground water, and the two constituents are generally reported together. Both are essential for nutrition, and recommended limits are set entirely for esthetic and taste considerations. Iron and manganese tend to precipitate as hydroxides and stain laundry and porcelain fixtures. Iron bacteria, such as Crenothrix, Callionella, utilizing iron as a source of energy, can colonize in wells and water pipes where iron concentrations exceed 0.2 mg/l. 14)

The states most plagued by excessive iron and manganese in drinking water are Washington, Oregon, and Idaho. Lesser problems occur in the Plains states. Problems of iron and manganese are tolerated by most users in the absence of better quality water. Generally, no obvious relation exists between type, age, and depth of the aquifer and high iron concentration. Ground water in the basalt rock of the Columbia River Group in Washington, Oregon, and Idaho, for example, contains only a small amount of iron. 15) In contrast, ground water in sedimentary rocks and alluvial de-

Table 9. HOUSEHOLD DAMAGES CAUSED BY USE OF MINERALIZED SURFACE AND GROUND WATER IN 1970.[13)]

Total Household Damage, Million $

State	Public Water Supply Treated Surface Water	Public Water Supply Treated Ground Water	Private Well	Total
Colorado	9.0	2.2	8.0	19.1
Idaho	0.4	3.3	2.8	6.5
Montana	2.3	1.3	2.3	5.9
Oregon	0.6	1.5	1.7	3.9
Washington	3.1	9.3	2.4	14.8
Wyoming	0.9	1.3	1.6	3.9
Total:	16.3	18.9	18.8	54.1

Per Capita Household Damage, $

State	Public Water Supply Treated Surface Water	Public Water Supply Treated Ground Water	Private Well	Total
Colorado	5.33	7.24	36.09	8.67
Idaho	5.71	7.74	12.66	9.08
Montana	6.94	8.86	10.83	8.54
Oregon	0.55	3.29	3.29	1.85
Washington	1.64	8.28	5.79	4.33
Wyoming	7.93	9.96	19.76	11.68
Average:	4.68	7.56	14.74	7.36

posits frequently contains excessive iron and manganese. In Snohomish and Whatcom Counties in Washington, excessive iron in ground water in the unconsolidated aquifer is a regional problem affecting hundreds of domestic wells. Concentrations of iron up to 1.9 mg/l and manganese up to 2.9 mg/l are reported. 16)

Serious iron problems exist in the northern part of the Willamette Valley in Oregon, in Adams, Bent and Prowers Counties of Colorado, and in the alluvial aquifers of eastern Montana. 7,9,10) Iron, manganese, and iron bacteria cause problems for the Boise, Idaho municipal water-supply system. Sixteen of 37 public-supply wells produced water exceeding U. S. Public Health Service limits for iron and/or manganese. Water mains were found to be corroded and encrusted with ferric or manganic oxides, and the system yielded "red water" under certain flow conditions. 17) Management and treatment of such water quality problems is very costly.

Fluoride

Fluoride is a constituent of fluorite found in sedimentary rocks and of cryolite in igneous rocks. It is widely present in ground water. Fluorides in sufficient quantity are toxic to humans and may cause fluorosis and bone damage. Low concentrations of 0.8 to 1.5 mg/l of fluoride in drinking water aids reduction of dental decay and are considered beneficial. Higher concentrations, up to 5 mg/l, may cause mottling of teeth but no harmful effects. 14) U. S. Public Health Service drinking water standards set a mandatory limit on fluoride that ranges from 0.8 to 1.7 mg/l based on prevailing air temperature. More water is drunk in warmer climates; thus, the fluoride content should be lower to prevent excessive total fluoride intake.

The fluoride content of ground water on a county-wide basis in the Northwest is shown on Figure 23. Maximum (not average) values are given as of 1962. It is evident that more high fluoride ground water is present in Montana, Wyoming, and Colorado than in the other states.

A review of water supplied by 173 municipalities in Montana shows that 19 water wells belonging to 10 communities produce water with a fluoride content of 1.5 mg/l and over. Maximum concentrations range to 6.4 mg/l. 9) High fluoride concentrations in ground water occur in northern and northeastern Montana, mainly in the Hell Creek and Fort Union Formations within the Missouri River basin. 19)

In Wyoming, high fluoride in ground water is common in the

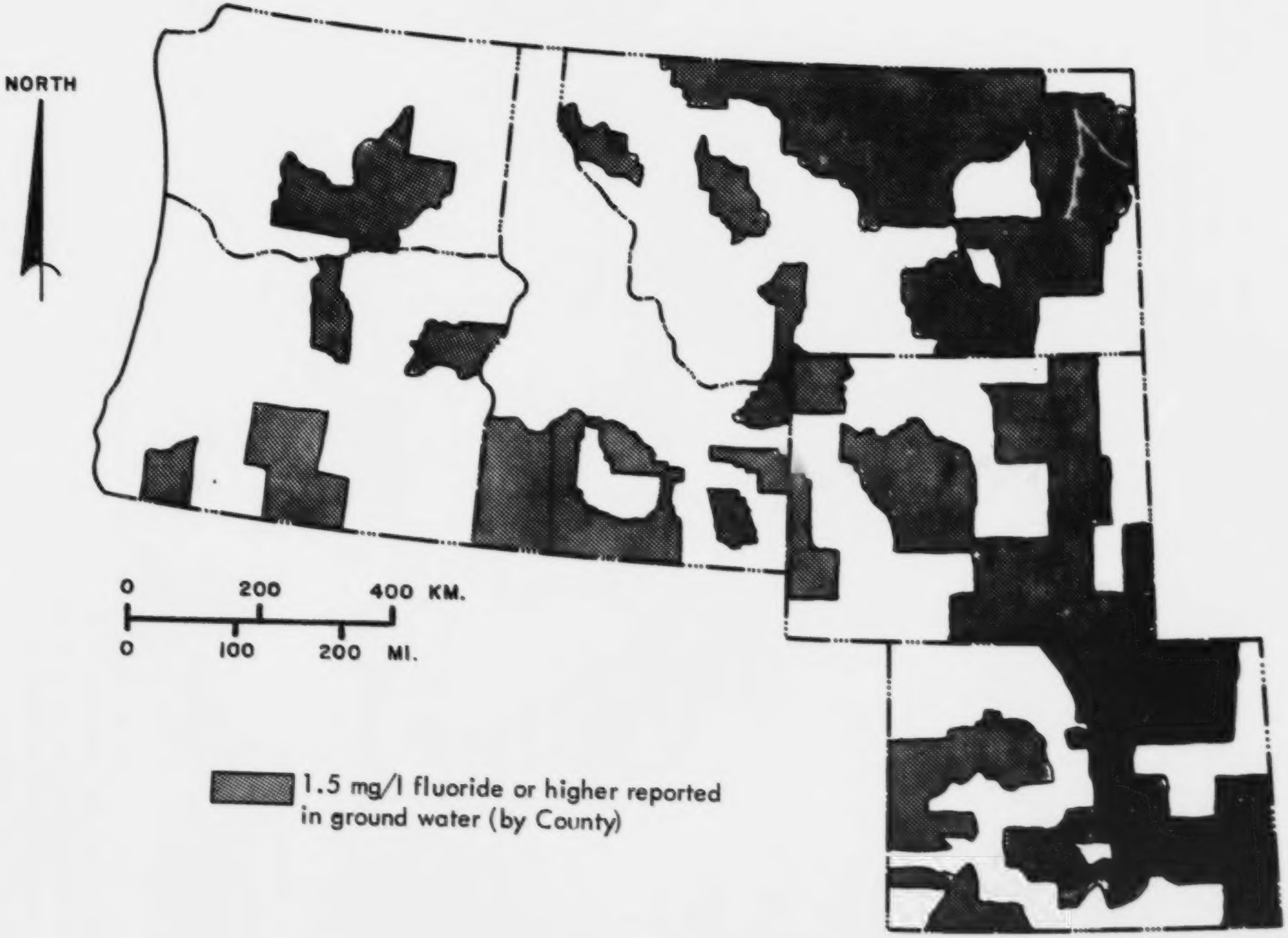
NORTH
0
200
400 KM.
0
100
200 MI.
1.5 mg/l fluoride or higher reported in ground water (by County)

Figure 23. Fluoride content of ground water in the Northwest. 18)

Green River basin. Concentrations range from 6.5 to 14 mg/l in the Wasatch Formation, an artesian aquifer that extends over 1,500 sq km (600 sq mi) in the northern part of the basin. 20) In northeastern Wyoming, many regional sedimentary aquifers are occasionally high in fluoride. 21) The Madison Formation in the Powder River basin also contains high fluoride concentrations. Analyses of water from 15 wells finished in the Madison Formation showed a range in fluoride concentration of 3.2 to 5.0 mg/l. 13)

In Colorado, excessive fluoride content occurs locally in various aquifers. Of regional impact are high fluoride levels in the deep artesian aquifer in the San Luis Valley. 22) Figure 24 shows the extent of 2 mg/l and 5 mg/l concentrations of fluoride in ground water in this valley. The area underlain by high fluoride ground water is over 1,000 sq km (400 sq mi). Values as high as 13 mg/l have been recorded.

In Idaho, high fluorides are a problem in a majority of water wells tapping the basalt aquifer in northern Owyhee County. 23) Similar problems exist locally elsewhere in the Snake River basin. 24) The common range of fluoride in the basalt of the Columbia River Group, which extends over 130,000 sq km (50,000 sq mi) of Idaho, Oregon, and Washington, is from 0.2 to about 0.8 mg/l. In the synclinal basins of eastern Oregon and Washington, the basalts contain ground water with a fluoride content ranging from 0.7 to 2.0 mg/l. Warm and hot waters of springs and wells contain above average amounts of fluoride. High fluoride is also reported in ground water in basalt rock below 300 m (1,000 ft). 15) Below the Columbia Basin Irrigation Project, ground water in the deeper zones contains fluoride in concentrations above 1.0 mg/l, and the water from some wells exceeds U. S. Public Health Service limits. 25)

Trace Metals

The geologic rocks and structures in the region, affected by wide-spread igneous intrusions, contain numerous deposits of copper, zinc, gold, silver, chromium, and other metals. Erosion, glaciation, and volcanic emanations have dispersed many minerals over the land surface. Small quantities are found in rocks and unconsolidated deposits. Ground water generally only contains traces of such metallic elements, and analyses to detect the presence of such constituents are not routinely undertaken. Most ground-water supplies in mining regions, such as the Colorado Plateau, are developed for mining and milling operations; wells in those locations are drilled into or adjacent to ore bodies and conceivably could yield quantities of ground water with appreciable min-

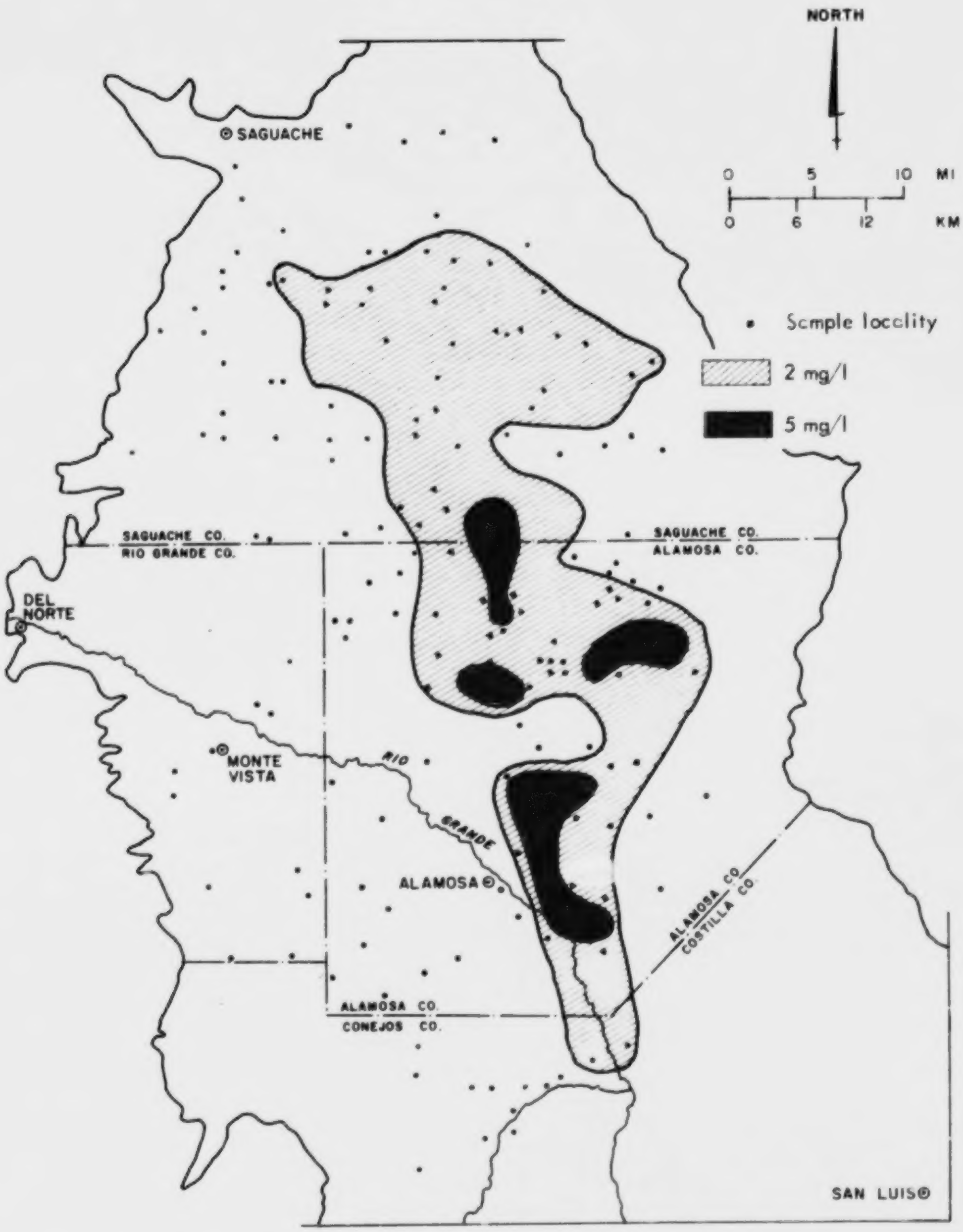
NORTH
0 5 10 MI
0 6 12 KM
● Sample locality
▨ 2 mg/l
■ 5 mg/l
SAGUACHE
SAGUACHE CO.
RIO GRANDE CO.
SAGUACHE CO.
ALAMOSA CO.
DEL NORTE
MONTE VISTA
RIO GRANDE
ALAMOSA
ALAMOSA CO.
COSTILLA CO.
ALAMOSA CO.
CONEJOS CO.
SAN LUIS

Figure 24. Fluoride concentration of ground water in the confined aquifer, San Luis Valley, Colorado. 22)

eral content.

Some of the more common trace metals are selenium, cadmium, and lead. Unfortunately, few problems of excessive concentrations of trace elements in ground water are documented. Selenium is believed to be highly toxic to man, and symptoms of selenium poisoning are similar to those of arsenic poisoning. In trace amounts, however, selenium appears to be an essential nutritional element. U. S. Public Health Service drinking water standards call for a mandatory limit of 0.01 mg/l. Excessive selenium (over 0.5 mg/l) in water is potentially dangerous to livestock. 14)

In the Northwest, a regional selenium problem exists in the Casper, Wyoming area. Selenium in concentrations exceeding 0.01 mg/l is present in an area of about 1,900 sq km (750 sq mi). Part of the selenium seems to have originated from surface-water runoff and irrigation, but high selenium concentrations are found locally in ground water from rocks of Cretaceous age and alluvium. 26) In Colorado, selenium concentrations greater than U. S. Public Health Service limits are present locally in the valley-fill and alluvial aquifers of the South Platte and Arkansas River valleys. The municipal water wells of Fort Morgan and Las Animas, for example, yield water with 0.04 mg/l and 0.023 mg/l of selenium, respectively. 10)

The presence of molybdenum in water is currently being studied by the University of Colorado and Colorado State University. 27) Most molybdenum released to the environment appears to originate in molybdenum mines and uranium and copper mining activities, and there is no information on the natural molybdenum content of ground water.

Radionuclides

Naturally radioactive substances in ground water are present in almost all rocks even though the amounts are often below detection limits. Development of the nuclear industry, nuclear weapons testing, and the related increase of radioactivity in the environment from fallout, required that limits be set on human exposure to radiation.

The Federal Radiation Council has provided criteria in establishing limits for radioactivity in drinking water. These limits are based upon three ranges of intake of radioactivity. For each range, a measure of control action has been defined as shown below:

Ranges of transient rates of daily intake	Graded Scale of Action
Range I	Periodic confirmatory surveillance as necessary
Range II	Quantitative surveillance and routine control
Range III	Evaluation and application of additional control measures as necessary

Limits have been set for daily intakes of radionuclides with the provision that dose rates be averaged over a period of one year. In the case of drinking water, recommended limits have been established for only two nuclides, namely Radium-226 (3 picocuries per liter) and Strontium-90 (10 picocuries per liter). The accumulation of excessive radium and strontium from water constitutes a health hazard. These radionuclides ingested into the body are retained and deposited in the bones, and ultimately may produce bone cancer. Although a great variety of radionuclides may be present in drinking water, it has not been considered necessary to establish limits for those other than Radium-226 and Strontium-90.

Levels of uranium, radium, and tritium in ground water have been studied by the U. S. Geological Survey. 28,29) Although incomplete so far as sampling coverage, these early studies showed no excessive amount of radioactivity in ground water in the Northwest.

Later studies carried out by the Colorado Department of Health have indicated that excessive radium is present in the Dakota Sandstone in southeastern Colorado. 30) Hundreds of wells in Pueblo County tap the aquifer for domestic water supply and it is common to find wells that yield above 10 picocuries per liter. Of 154 wells sampled in the 1972-73 period, 79 exceeded the 3 picocuries limit; one well measured 400 picocuries per liter. Broken down according to Federal radiation guides, the result of the survey was as follows:

	Range	Picocuries/day	Number of Wells
	I	0 - 2	36
	II	2 - 20	80
	III	20 - 200	36
in excess of	III	200	2

Studies have shown no relation between radium concentration and well depth. Owners of wells with water exceeding 3 picocuries per liter have been advised by local health departments to discontinue drinking the water. Indications are that there is excessive Radium-226 in ground water in at least four other southeastern Colorado counties. Occasionally in the Northwest, analyses of ground water do indicate some local presence of radium in well water but the Pueblo County situation is by far the most serious case of radionuclides. Many thermal wells and hot springs yield water with high radium concentrations.

Arsenic

Arsenic is present as native arsenic or arsenopyrite. Arsenic oxide is derived as a by-product in the smelting of arsenic ores for copper, gold, lead, and silver. Arsenic is notorious for its toxicity to humans. The U. S. Public Health Service recommended limit for drinking water is 0.01 mg/l, with a mandatory limit of 0.05 mg/l. However, the constituent is not normally included in analyses.

A problem of regional significance exists in Lane County, Oregon, where arsenic in ground water appears to be related to the Fisher Formation comprised of volcanic deposits. 31) An area of about 260 sq km (100 sq mi) is known to be underlain by ground water high in arsenic content (Figure 25). A survey of 174 wells indicated that 53 wells yielded water with an arsenic concentration higher than 0.01 mg/l. The largest concentration of arsenic was 1.7 mg/l. It is thought that the arsenic probably accumulated as volcanic dust during the deposition of the Fisher Formation and was later released as a result of chemical alteration.

Isolated cases of arsenic in ground water used for municipal supplies are reported in Wyoming. Reported concentrations ranged from 0.01 to 0.02 mg/l. 32)

Thermal Springs

Thermal springs and wells are indicators of possible geothermal resources. Springs and wells are called thermal when their temperature is at least 8°C (15°F) above the mean annual air temperature at their locality. There are several hundred such thermal springs in the Northwest. 33) Their distribution is shown in Figure 26. Hot springs are common in extensive areas of lava flows in eastern Oregon, in Idaho, and Yellowstone National Park in Wyoming. They are also common in areas where the rocks have been intensely folded and faulted in geologically recent time (Montana, Colorado).

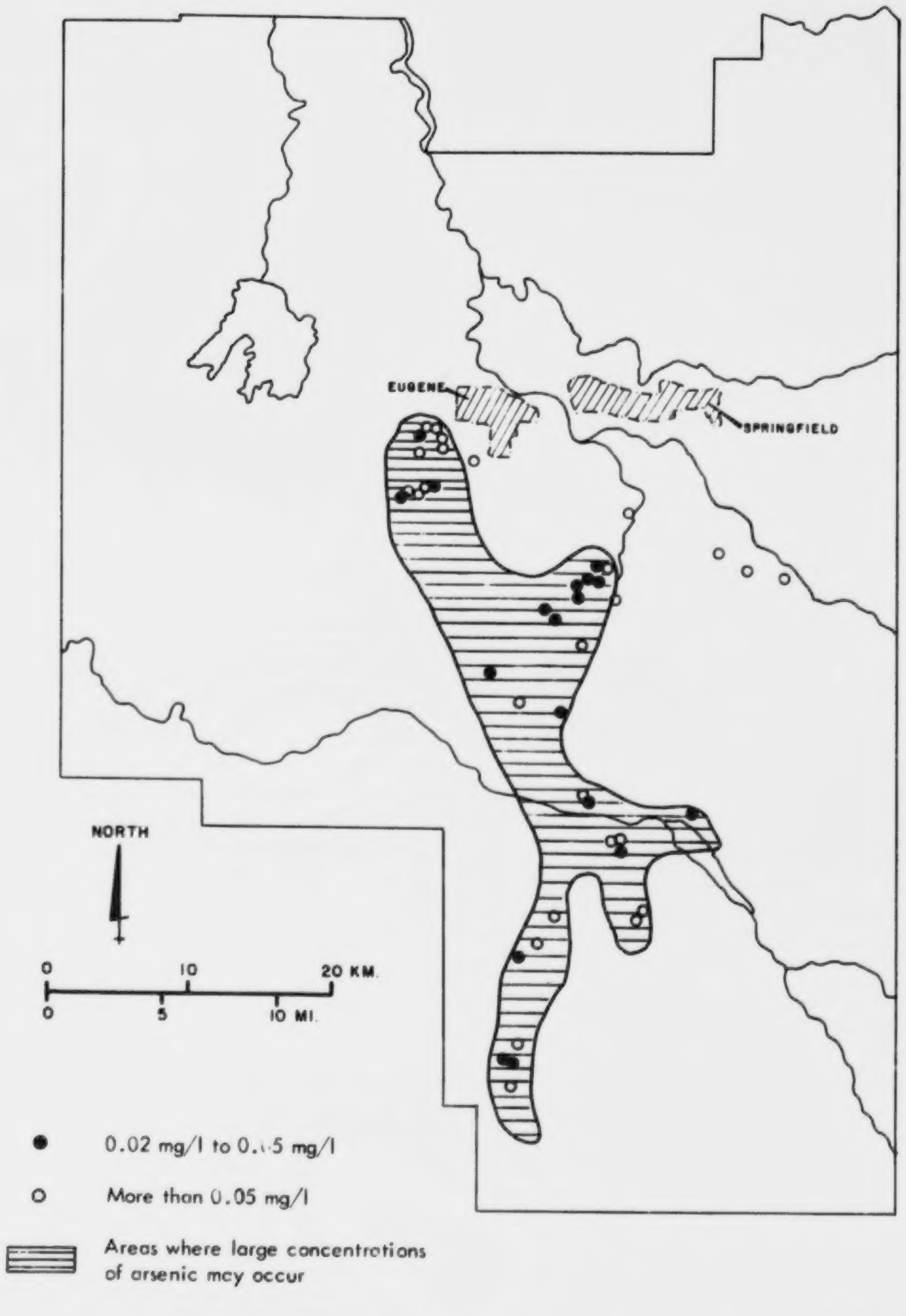
EUGENE
SPRINGFIELD
NORTH
0
10
20 KM.
0
5
10 MI.
● 0.02 mg/l to 0.05 mg/l
○ More than 0.05 mg/l
Areas where large concentrations of arsenic may occur

Figure 25. Arsenic in ground water of Lane County, Oregon. [31)]

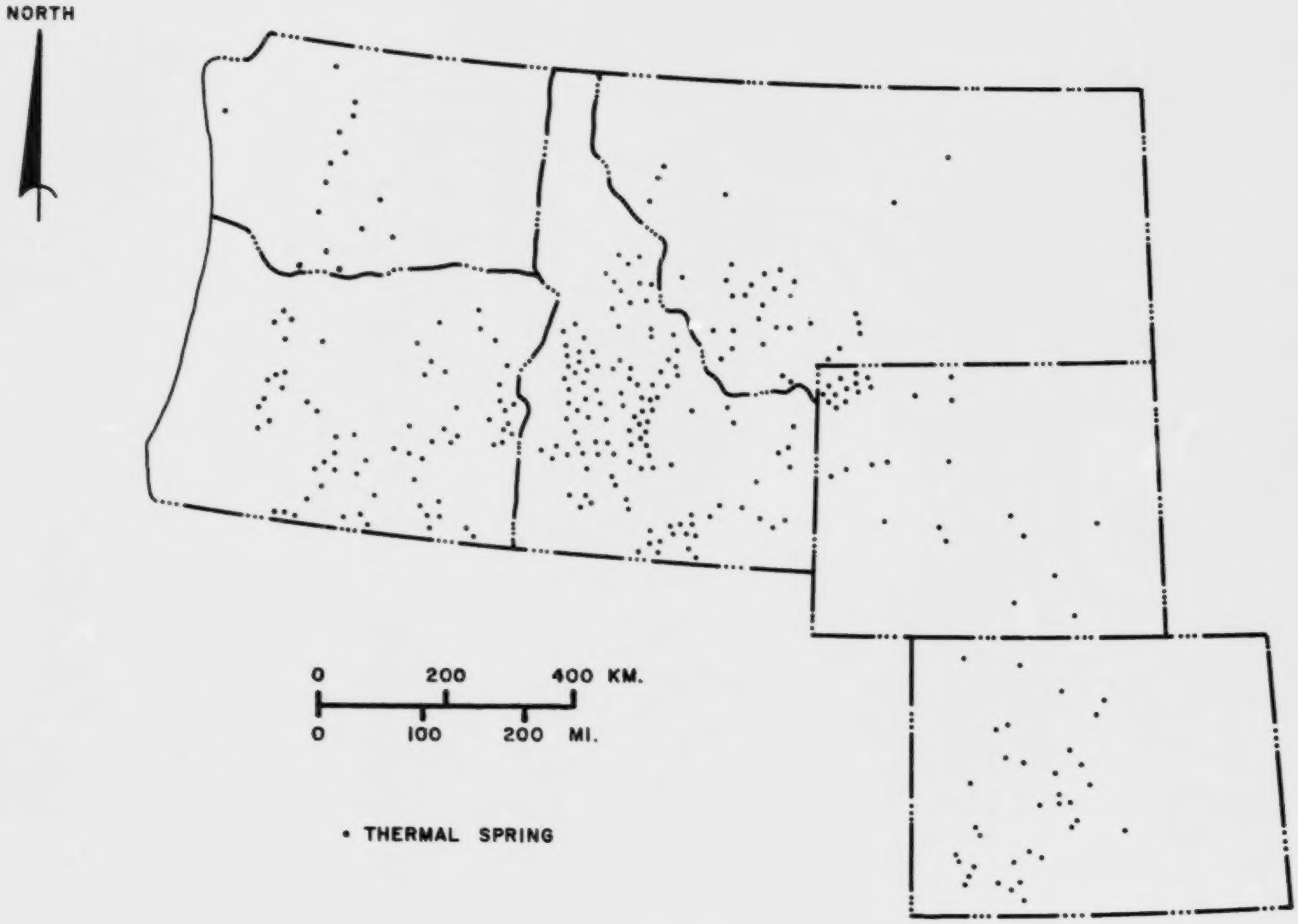
NORTH
0
200
400 KM.
0
100
200 MI.
• THERMAL SPRING

Figure 26. Distribution of thermal springs in the Northwest. 33)

Because of the high mineral content of ground water, these thermal springs represent point sources of natural pollution. In many areas, thermal springs are significant contributors of salts to surface water drainage features. On the other hand, the elevated temperature of thermal ground water is generally considered to be a favorable factor. Thermal water from springs and wells is used for heating, bathing, and irrigation, and in some places, for drinking (bottled water).

In Colorado there are some 200 thermal springs located mainly in faulted Paleozoic and Cretaceous rocks of the Rocky Mountains and associated with igneous rock throughout the western part of the state. The location of major thermal springs in western Colorado is shown on Figure 27, and their characteristics are shown in Table 10. Glenwood Springs is the largest group of springs, with a total discharge of 240 l/s (4,000 gpm). 34) In Idaho there are numerous hot springs in the central mountain region. In the Bruneau River valley, many warm springs rise through overlying lake sediments or directly from the lava. At least 380 hot springs and wells are known to occur in central and southern Idaho. 35) In the city of Boise, 200 houses are heated from a supply of 53 l/s (1,200,000 gpd) of 77°C (170°F) water. 36) A summary of chemical analyses of thermal waters from springs and wells in Idaho is shown in Table 11. The quality of thermal ground water in Idaho is remarkably good. In a survey of 124 springs and wells, dissolved solids concentrations ranged from 14 to 13,700 mg/l and averaged 812 mg/l. However, for the wells and springs in the survey in the southeastern part of the state, waters were much more mineralized with dissolved solids concentrations reaching 13,700 mg/l and averaging 3,510 mg/l.

In Montana, several warm springs issue from folded and faulted rocks of Paleozoic age and others from Cretaceous beds. The largest is Warm Springs, with a temperature of 20°C (68°F) and a discharge of 5,050 l/s (80,000 gpm). Smaller warm springs are associated with lava beds in valleys. Temperatures of the thermal ground water are generally not high.

In Oregon some 86 thermal springs and wells were inventoried in 1965, 17 of which flowed in excess of 63 l/s (1,000 gpm). 33) In the southeastern part of the state, warm and hot springs rise through lake deposits or valley alluvium along faults in underlying lava. In this region, Columbia River Group basalt flows are folded and faulted, forming tilted block mountains and grabens. Principal areas of thermal spring activity are Klamath Falls, Lakeview, Warner Valley, Alvord Valley, and the Harney Basin. Small warm springs

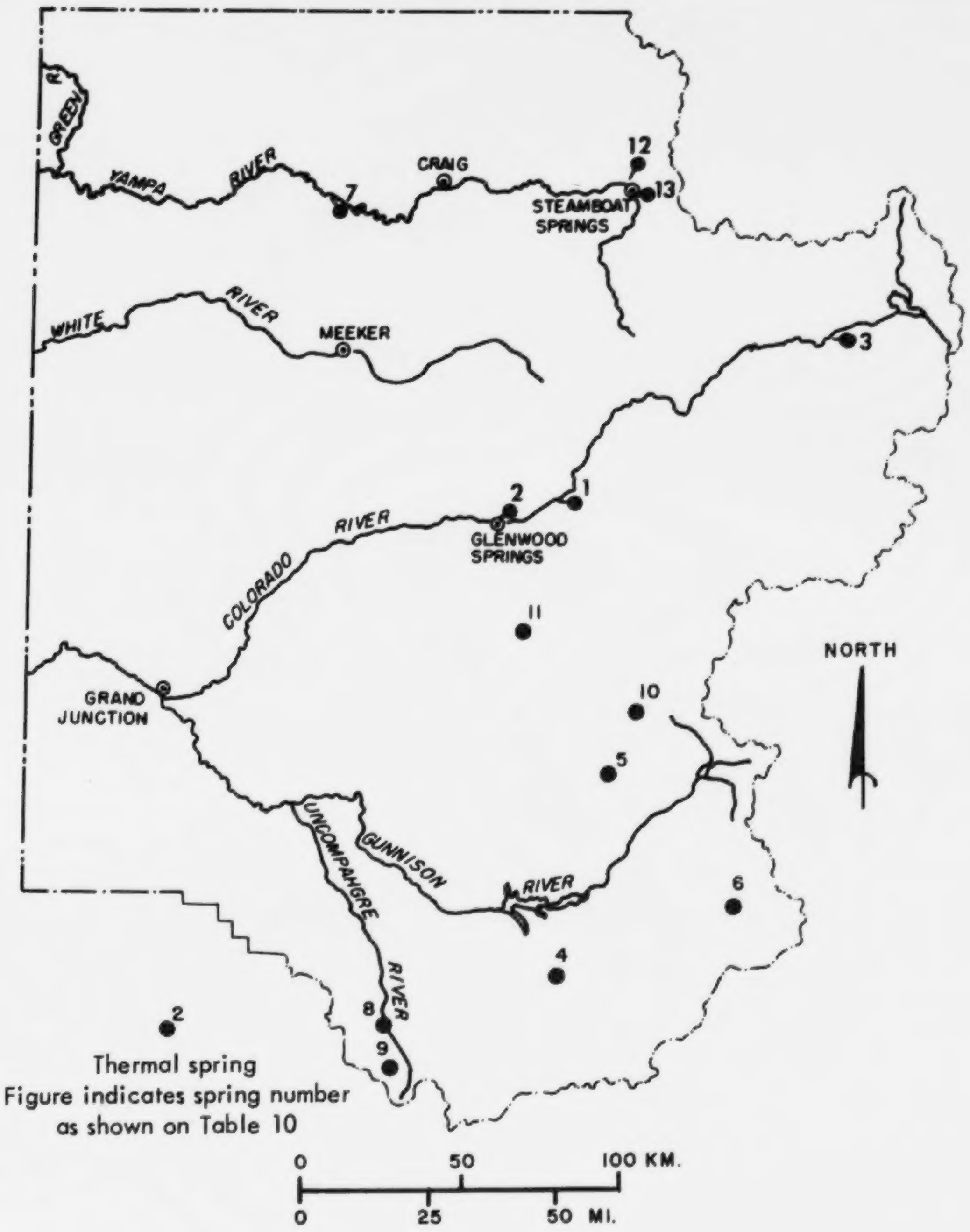
GREEN R.
YAMPA RIVER
CRAIG
12
13
7
STEAMBOAT SPRINGS
WHITE RIVER
MEEKER
3
2
1
COLORADO RIVER
GLENWOOD SPRINGS
11
NORTH
10
GRAND JUNCTION
5
GUNNISON RIVER
UNCOMPAHGRE RIVER
6
4
8
9
2
Thermal spring
Figure indicates spring number
as shown on Table 10
0
50
100 KM.
0
25
50 MI.

Figure 27. Location of major thermal springs in western Colorado. 34)

Table 10. QUALITY OF THERMAL SPRING WATER IN WESTERN COLORADO. 34)

Map No.	Name of spring	Range in temperature °C	°F	Cumulative discharge l/s	gpm	Range of dissolved solids mg/l	Principal cation and anion
1	Dotsero Springs	28.5 - 31.5	83 - 89	32	500	10,660 - 10,720	Sodium Chloride
2	Glenwood Springs	34.5 - 65.5	94 - 150	250	4,000	17,300 - 24,240	Sodium Chloride
3	Hot Sulphur Springs	35.5 - 45.5	96 - 114	6	100	742 - 1,560	Sodium Bicarbonate
4	Cebolla Hot Springs	9.0 - 46.0	48 - 115	6	100	1,600 - 2,600	Sodium Bicarbonate
5	Cement Creek Springs	24.5 - 28.5	76 - 83	22	350	529 - 689	Calcium Bicarbonate
6	Waunita Hot Springs	62.5 - 77.5	145 - 172	63	1,000	556 - 559	Sodium Sulfate
7	Juniper Hot Springs	35.0 - 41.0	95 - 106	3	50	1,160 - 1,690	Sodium Bicarbonate
8	Orvis Hot Springs	52.0 - 53.8	126 - 129	2	35	700 - 2,500	Sodium Sulfate
9	Ouray Hot Springs	33.0 - 82.0	91 - 180	50	800	1,000 - 1,700	Calcium Sulfate
10	Conundrum Hot Springs	38.0	100	8.2	130	2,310	Calcium Sulfate
11	Penny Hot Springs (Avalanche Hot Springs)	44.5 - 56.5	112 - 134	16	250	2,480 - 2,850	Calcium Sulfate
12	Routt Hot Springs	64.0 - 64.5	147 - 148	16	250	458 - 602	Sodium Chloride
13	Steamboat Springs	39.5 - 40.0	103 - 104	126	2,000	884 - 1,520	Sodium Chloride
	Steamboat Springs	15.0 - 30.5	59 - 87	-	-	1,900 - 6,180	Sodium Bicarbonate

Table 11 . TABULATION OF SELECTED CHEMICAL ANALYSES OF THERMAL GROUND WATER IN COLORADO, IDAHO AND WYOMING. Concentrations in mg l (milligrams per liter).

	Temperature				Dissolved Solids (calculated)			Chloride (Cl)		
		°F	°F	°C						
State	N	R	M	M	N	R	M	N	R	M
Colorado	13	70 - 168	150	66	-	-	-	13	7 - 11,025	103
Idaho	124	54 - 199	117	47	124	14 - 13,700	344	124	1.1 - 7,700	14
Wyoming (exclusive of Yellowstone Park)	8	60 - 160	127	53	-	-	-	8	20 - 2,000	324

	Hardness (CaCO$_3$)			Alkalinity (CaCO$_3$)			Iron (Fe)		
State	N	R	M	N	R	M	N	R	M
Colorado	13	20 - 1,450	244	12	30 - 908	162	-	-	-
Idaho	124	1 - 3,000	14	123	9 - 2,050	137	-	-	-
Wyoming (exclusive of Yellowstone Park)	8	35 - 1,280	918	8	57 - 814	305	5	0.03 - 0.2	-

N - Number of samples
R - Common range
M - Median

Table 11 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF THERMAL GROUND WATER IN COLORADO, IDAHO AND WYOMING. Concentrations in mg/l (milligrams per liter).

	Sodium (Na)			Sulfate (SO_4)			Nitrate (NO_3)		
State	N	R	M	N	R	M	N	R	M
Colorado	11	17 - 525	162	13	38 - 1,504	199	-	-	-
Idaho	123	3.9 - 4,300	87	124	2.2 - 980	33	123	0 - 1.6	0.06
Wyoming (exclusive of Yellowstone Park)	8	33 - 1,500	266	8	12 - 1,430	568	7	0.1 - <10	0.1

	Fluoride (F)			pH		
State	N	R	M	N	R	M
Colorado	-	-	-	-	-	-
Idaho	124	0.1 - 30	6.5	121	6.3 - 9.8	7.8
Wyoming (exclusive of Yellowstone Park)	8	2 - 10	3.5	7	6.2 - 8.2	7.1

rise near Mount Hood along the Cascade Mountains and in the Blue Mountains of northeastern Oregon. In the Klamath Falls area, about 400 wells varying in depth from 30 to 550 m (100 to 1,800 ft) tap high temperature ground water ranging up to 133°C (235°F). 37)

Thermal spring activity in Washington is rather small. There are at least 35 mineral and warm springs, but only a few have been studied. Most are associated with lava flows in the Cascade Range; other warm springs exist on the Olympic Peninsula.

In Wyoming, some 100 geysers and hot springs, deriving their heat from magma that underlies thick lava beds, are active in Yellowstone National Park. In central Wyoming about 30 thermal springs issue from faulted sedimentary rocks. The Big Horn or Thermopolis Springs are among the largest in the country. The major spring in the area discharges 800 l/s (12,600 gpm) and has a temperature of 57°C (135°F). The water probably originates in the Tensleep Sandstone. Chemical analyses of selected thermal springs outside of Yellowstone Park are listed in Table 11.

As mentioned above, the principal impact of thermal groundwater discharge on water quality is the quantity of dissolved minerals added to surface-water runoff. A case in point is western Colorado. Fourteen major thermal springs in the upper drainage basins of the Colorado, Gunnison, Uncompahgre, and Yampa Rivers discharge more than 57 million cu m (46,000 acre-ft) per year of saline hot water to the rivers. The temperature of this water ranges up to 82°C (180°F), and the dissolved solids content ranges from 458 to 24,240 mg/l. More than 450,000 metric tons (500,000 tons) of salt is contributed each year to these rivers by thermal springs (Table 12). The springs contribute about 30 percent of the annual dissolved solids load of the Upper Colorado River above Cameo and about 8.5 percent of the dissolved solids load of the Yampa River.

BASE-LINE GROUND-WATER QUALITY CONDITIONS

Natural ground-water quality conditions in each of the six project states are discussed below. The description of chemical quality of ground water is based on a review of the literature. Most of the studies on ground-water quality in the Northwest are less than 20 years old, as comparatively few ground-water investigations were carried out prior to 1954. Many studies were made specifically to investigate the feasibility of using ground water for irrigation in relatively small areas, and these data are of limited interest

Table 12. DISCHARGE, DISSOLVED SOLIDS LOAD, AND DISSOLVED SOLIDS CONCENTRATION OF THERMAL SPRINGS IN WESTERN COLORADO. 34)

	Discharge	
River Basin	Cubic meters per day	Acre-feet per year
Upper Colorado above Cameo	122,350	36,200
Gunnison	17,130	5,070
Yampa	17,130	5,070
Total:	156,610	46,340

	Dissolved Solids		
	Load		
River Basin	Metric tons per year	Tons per year	Concentration mg/l
Upper Colorado above Cameo	432,000	476,000	9,700
Gunnison	5,400	6,000	870
Yampa	31,300	34,500	5,000
Total:	468,700	516,500	

only.

In recent years, larger regional ground-water investigations have shed light on both quantity and quality of available resources. Because of the paucity of historical records, true base-line data are either not available or of doubtful nature. Changes in ground-water quality due to man's activities have taken place, especially in water-table aquifers subject to impact from irrigation and urbanization. The quality of water in the deeper sedimentary, volcanic, and crystalline aquifers probably best approaches base-line quality standards.

Colorado

Serious ground-water quality problems exist in Colorado. Large portions of the state are underlain by saline ground water (Figure 28), and the quality of water in the major alluvial aquifers is deteriorating. A general description of ground-water quality in each of the principal ground-water provinces is given below. Table 13 is a compilation of chemical analyses of selected constituents in natural ground waters.

South Platte River Basin -

The average total dissolved solids content of ground water in the alluvial aquifer in the South Platte River basin near Denver is about 1,300 mg/l and increases to about 1,800 mg/l at the state line. This water is unsuitable for domestic and municipal supplies, but it is utilized where better quality water is not available. Although pumped for irrigation, some of the water is of salinity hazard classification. The water quality of some community well systems that tap the alluvial aquifer in the South Platte River valley is shown in Table 14. The actual chemical composition of water in the valley-fill aquifers varies greatly, even within local areas. Generally, the total hardness exceeds 200 mg/l, and concentrations of total dissolved solids and sulfate exceed the U. S. Public Health Service recommended upper limits for drinking water (500 mg/l and 250 mg/l, respectively).

In the main South Platte River valley between the Weld County line and the town of Gilcrest, total dissolved solids range from 687 to 1,840 mg/l, sulfate ranges from 182 to 329 mg/l, and chlorides from 76 to 156 mg/l. Further downstream, from Gilcrest to the state line, total dissolved solids in the shallow aquifer range from 743 to 4,010 mg/l, sulfate from 329 to 2,210 mg/l, and chlorides are generally less than 75 mg/l. 38)

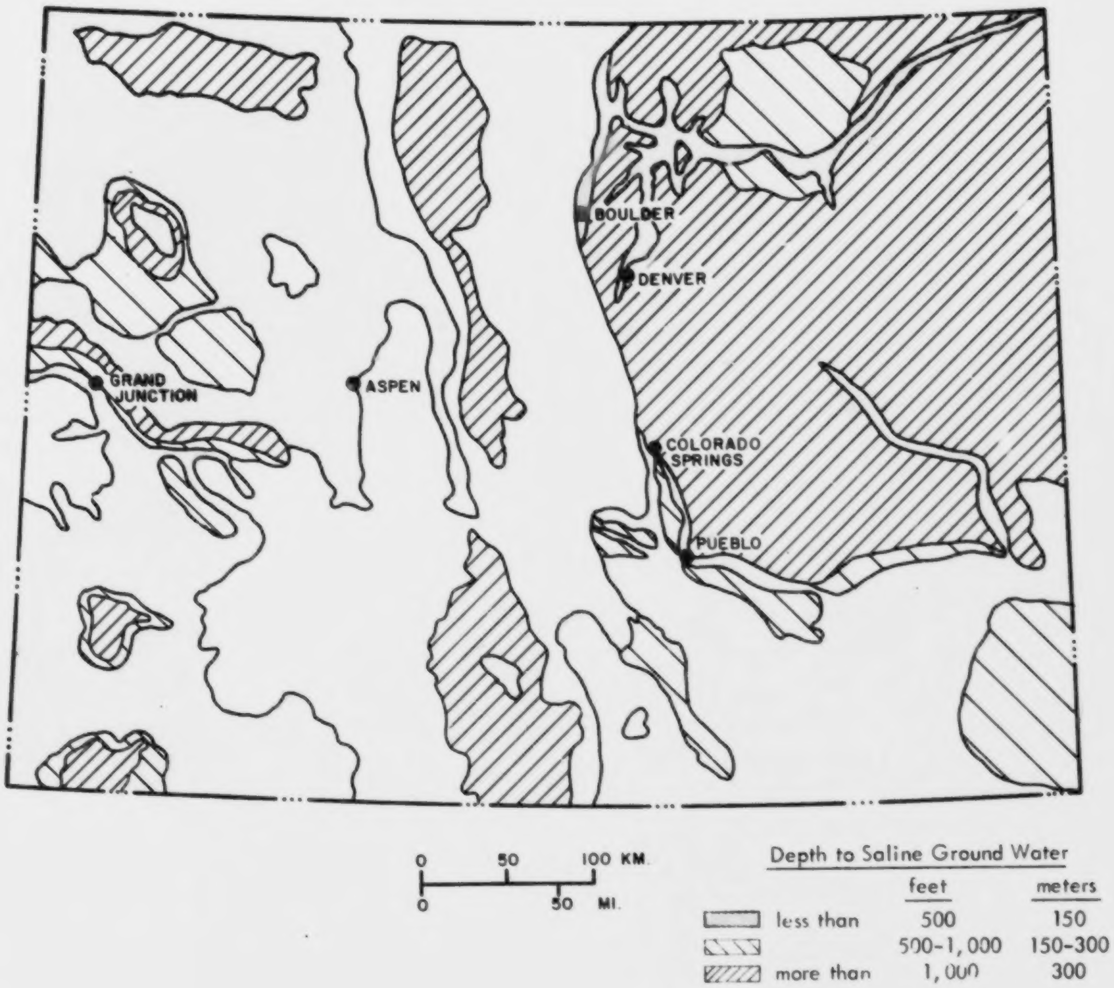
BOULDER
DENVER
COLORADO SPRINGS
PUEBLO
ASPEN
GRAND JUNCTION
0 50 100 KM.
0 50 MI.
Depth to Saline Ground Water
feet
meters
less than 500 150
500-1,000 150-300
more than 1,000 300

Figure 28. Colorado - Depth to ground water containing more than 1,000 mg/l dissolved solids 2)

Table 13 . TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN COLORADO. Concentrations in mg/l (milligrams per liter). 39 through 44)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
	N	R	M	N	R	M	N	R	M
Northern High Plains									
Ogallala Formation	8	205 - 304	239	8	2.4 - 9.4	2.8	8	124 - 172	142
South Platte Basin									
Alluvium	27	402 - 8,910 a)	1,430	27	5.2 - 235	32	27	253 - 3,410	860
Pierre Shale	6	204 - 2,490 a)	-	6	3.0 - 560	-	6	14 - 949	-
Denver Basin									
Alluvium	106	141 - 2,870 a)	880	155	0 - 1,400	86	147	83 - 1,800	416
Dawson Formation	76	148 - 2,020 a)	238	109	1.0 - 385	6.0	104	3 - 1,240	40
Laramie Formation	5	448 - 3,680 a)	-	9	6.0 - 3,060	67	7	6 - 526	24
Laramie Formation and Fox Hills Sandstone	20	371 - 1,300 a)	596	22	13 - 454	64	22	3 - 32	9
Precambrian Crystalline Rocks	5	134 - 50,500 a)	-	8	1.0 - 30,200	3.0	8	28 - 12,700	100
Northern Arkansas Basin									
Alluvium	42	444 - 5,610 a)	2,810	42	9.2 - 250	78	42	288 - 2,260	1,460
San Luis Valley									
Valley fill - unconfined	105	72 - 27,900 b)	263	206	0.3 - 5,220	7.5	185	10 - 4,350	161
Valley fill - confined	93	60 - 2,440 b)	191	130	0.5 - 181	1.9	175	2 - 360	38
Piceance Basin									
Green River Formation	17	502 - 6,880 b)	805	17	3.0 - 761	12	17	27 - 825	106

N - Number of samples
R - Range
M - Median

a) Calculated
b) Sum

Table 13 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN COLORADO. Concentrations in mg/l (milligrams per liter). [39 through 44])

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Northern High Plains									
Ogallala Formation	8	131 - 182	157	8	0.00 - 0.03	0.00	8	8.6 - 28	16
South Platte Basin									
Alluvium	27	162 - 541	280	9	0.00 - 0.02	0.01	4	104 - 228	-
Pierre Shale	6	120 - 649	-	5	0.00 - 2.40	-	4	22 - 640	-
Denver Basin									
Alluvium	102	35 - 1,402	265	64	0.00 - 12.7	0.03	111	10 - 562	111
Dawson Formation	76	24 - 385	164	71	0.00 - 6.0	0.11	81	6.2 - 1,050	82
Laramie Formation	7	123 - 558	393	2	0.11 - 4.9	-	7	101 - 2,040	294
Laramie Formation and Fox Hills Sandstone	22	285 - 569	419	20	0.00 - 1.6	0.10	19	138 - 492	231
Precambrian Crystalline Rocks	7	16 - 154	105	6	0.00 - 31	-	5	7.2 - 13,700	-
Northern Arkansas Basin									
Alluvium	42	120 - 376	266	-	-	-	42	21 - 919	338
San Luis Valley									
Valley fill - unconfined	92	21 - 7,717	240	-	-	-	131	2.5 - 10,400	29
Valley fill - confined	95	34 - 2,468	146	9	0.0 - 0.12	0.01	143	4.8 - 1,000	49
Piceance Basin									
Green River Formation	17	327 - 5,176	585	19	0.009 - 6	0.03	17	150 - 2,840	270

Table 13 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN COLORADO. Concentrations in mg/l (milligrams per liter). [39] through 44)

	Sulfate (SO_4)			Nitrate (NO_3)			Fluoride (F)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Northern High Plains									
Ogallala Formation	8	9.0 - 24	12	129	2.5 - 91	12	8	0.8 - 1.9	1.0
South Platte Basin									
Alluvium	27	54 - 5,750	742	27	3.9 - 180	28	4	0.8 - 2.3	-
Pierre Shale	6	1.2 - 1,550	-	6	0.00 - 5.6	-	4	0.3 - 3.2	-
Denver Basin									
Alluvium	129	10 - 1,270	200	97	0.1 - 66	16	101	0.1 - 8	1.0
Dawson Formation	99	0.0 - 1,960	20	75	0.0 - 57	0.3	76	0 - 4.4	1.2
Laramie Formation	7	2.5 - 1,960	53	6	0.0 - 8.5	-	6	1.0 - 3.6	-
Laramie Formation and Fox Hills Sandstone	22	0.6 - 189	4.4	17	0.0 - 3.5	0.1	18	1.0 - 10	2.2
Precambrian Crystalline Rocks	5	6.2 - 255	-	6	0.2 - 222	-	7	0.2 - 12	1.0
Northern Arkansas Basin									
Alluvium	42	186 - 3,470	1,710	42	0.3 - 56	18	42	0.6 - 8.9	1.6
San Luis Valley									
Valley fill - unconfined	115	0.6 - 11,680	30	182	0.2 - 138	4.4	205	0.0 - 20	0.4
Valley fill - confined	99	0.0 - 60	5.8	83	0.0 - 17	0.5	186	0.0 - 16	1.6
Piceance Basin									
Green River Formation	18	5.3 - 798	106	1	0.1	-	18	0.4 - 44	12

Table 13 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN COLORADO. Concentrations in mg/l (milligrams per liter). 39 through 44)

Location - Aquifer	Silica (SiO_2) N	Silica (SiO_2) R	Silica (SiO_2) M	pH N	pH R	pH M
Northern High Plains						
Ogallala Formation	8	24 - 55	43	8	7.5 - 7.8	7.7
South Platte Basin						
Alluvium	27	13 - 39	24	27	7.6 - 8.0	7.8
Pierre Shale	6	8.3 - 16	-	6	7.2 - 8.3	-
Denver Basin						
Alluvium	88	0 - 109	24	128	6.5 - 8.8	7.5
Dawson Formation	79	3.2 - 34	11	96	6.4 - 9.0	7.9
Laramie Formation	2	8.2 - 11	-	7	7.7 - 8.9	8.2
Laramie Formation and Fox Hills Sandstone	20	8.6 - 20	14	21	7.6 - 8.8	8.1
Precambrian Crystalline Rocks	5	18 - 83	-	7	6.7 - 7.7	7.1
Northern Arkansas Basin						
Alluvium	42	12 - 36	18	42	7.3 - 8.1	7.6
San Luis Valley						
Valley fill - unconfined	153	1.7 - 59	35	153	5.1 - 9.6	7.7
Valley fill - confined	182	15 - 131	54	186	6.8 - 9.5	8.0
Piceance Basin						
Green River Formation	16	0.2 - 22	12	-	-	-

In the southern tributary valleys of Weld County, the ground water is highly mineralized. In Boxelder Creek Valley, the total dissolved solids exceed 1,500 mg/l and range up to 2,960 mg/l. In the Prospect Valley area of Lost Creek valley, the total dissolved solids commonly exceed 1,000 mg/l and range up to 4,060 mg/l. In the southern part of the Prospect Valley area, the ground water is less mineralized, and its chemical quality is determined largely by recharge from storm runoff and seepage of South Platte River water into the aquifer. Good quality ground water occurs in less developed parts of some southern tributary valleys. For example, in lower Beaver Creek valley in Morgan County, the total dissolved solids of the valley-fill aquifer are only 119 mg/l.

The valley-fill aquifers in the northern tributary valleys of Lodgepole Creek and upper Crow Creek contain waters with less than 400 mg/l of total dissolved solids. In the densely irrigated areas of lower Crow Creek valley, however, the total dissolved solids of the shallow ground water generally exceed 2,000 mg/l. In the valleys of Lone Tree and Spring Creeks of northwestern Weld County, mineralization increases in a downstream direction, from about 500 mg/l of total dissolved solids near Nunn to about 2,000 mg/l in the lower end of Lone Tree Creek valley.

In the heavily irrigated areas of the lower Cache la Poudre drainage basin, total dissolved solids in the valley-fill deposits exceed 2,000 mg/l, and sulfate concentrations commonly exceed 1,200 mg/l. These sulfate concentrations are produced by solution of evaporites (gypsum) present in the shallow aquifers.

Water quality in the White River Group and Ogallala Formation of Tertiary age is generally good. Total dissolved solids in these formations range from 200 to 450 mg/l, and the total hardness is generally less than 200 mg/l.

The quality of water in underlying Cretaceous bedrock formations varies greatly. Better quality water occurs at or near the outcrop and recharge areas, and the quality deteriorates with depth and distance from the recharge area. The hardness of these ground waters is generally lower than that in the valley-fill aquifer; however, high concentrations of sulfate are common in water from the Pierre, Fox Hills, and Laramie formations in northwestern Larimer, north-central Weld, and northern Morgan Counties.

Arkansas River Valley -

Similar to conditions in the South Platte River valley, the quality of the ground water in the alluvial aquifer generally deteriorates in a downstream direction. For example, the total dissolved solids, which average 500 mg/l near Pueblo, increase to over 4,000 mg/l at the Kansas state line. The water is not suitable for drinking, but is used for this purpose in communities where no better quality water is available. Among these towns are La Junta, Las Animas, and Lamar (see Table 14). Poor water quality has slowed the growth of towns and industrial development in the river basin. Recently, the Federal Office of Saline Water carried out studies to examine the technical and economic feasibility of desalting these municipal water supplies. 10)

In contrast to the generally poor quality water available from the alluvial-fill aquifer, softer and less mineralized water can be obtained in some localities from the Cheyenne Sandstone of the Purgatoire Formation and the Dakota Sandstone, both of Cretaceous age. However, locally the ground water in these sandstones contains excessive hydrogen sulfide, iron, fluoride, and radionuclides.

In the southeast corner of the state, rocks of Triassic and Jurassic age contain some fresh water. These aquifers are tapped by relatively few wells.

Denver Basin -

The alluvial aquifers in the Denver basin area yield water of variable quality, controlled by the source of recharge. In the urban areas, the ground water in the alluvium is rather mineralized and of poor quality, but outside the city limits the ground water is of better quality with total dissolved solids of 200 to 400 mg/l. Ground water in the bedrock aquifers is of fair to good quality. Water from the upper part of the Dawson Formation frequently contains excessive iron and radioactive radon gas. The sand, gravel, and conglomerate of the lower part of the Dawson Formation yield fairly soft water. Concentrations of dissolved solids range from 200 to 1,200 mg/l. 42)

The Dawson and Laramie Formations contain carbonaceous debris, coal, and soluble minerals; water from these zones contains objectionable amounts of dissolved minerals including iron, hydrogen sulfide, sodium manganese, silica, chloride, and calcium carbonate. The Laramie-Fox Hills sandstone sequence contains generally good quality water with total dissolved solids that range from 50 to 800 mg/l. In

Table 14. QUALITY OF GROUND WATER OF SOME MUNICIPAL SUPPLY SYSTEMS IN THE SOUTH PLATTE AND ARKANSAS RIVER VALLEYS, COLORADO - 1971. [10)]

		South Platte River Basin			Arkansas River Basin		
Characteristic	USPHS Standards [a)]	Brighton	Ft. Lupton	Ft. Morgan	La Junta	Las Animas	Lamar
Total dissolved solids	500 mg/l	1,331	1,221	1,692	1,953	3.075	597
Total hardness	-	619	553	920	962	1,762	354
Calcium (as $CaCO_3$)	-	438	400	713	888	1,020	380
Magnesium	-	44	41	51	76	180	18
Sodium	-	206	204	158	198	480	42
Sulfate	250	435	363	800	1,044	2,093	337
Iron	0.3	0.35	0.05	0.05	0.20	3.0	1.4
Fluoride	1.4 - 2.4 [b)]	1.2	1.4	0.9	1.3	1.6	0.8
Selenium	0.01 [b)]	0.002	0.002	0.04	0.007	0.023	0.006
Nitrate	45	72	45	30	10.5	2	19.5
Number of wells	-	10	4	8	12	4	15
Depth	-	11 - 20 m	15 - 16 m	53 - 77 m	12 m	8.5 - 9.4 m	13 - 28 m
Aquifer	-	S. Platte R. alluvium	S. Platte R. alluvium	S. Platte R. alluvium	Arkansas R. alluvium	Arkansas R. alluvium	Clay Creek alluvium
Population	-	8,309	2,489	7,594	7,938	3,148	7,797

a) U. S. Public Health Service Drinking Water Standards, 1962. Concentrations in excess of recommended limits are underlined.
b) Cause for rejection, all other values are limits.

areas where local geologic structure impedes ground-water circulation, the water may contain troublesome amounts of methane, hydrogen sulfide, iron, and fluoride.

High Plains -

The quality of the water in the Ogallala aquifer is good, with dissolved solids ranging from 100 to 500 mg/l, and a hardness ranging from 60 to 400 mg/l. 45) A high silica content is reported in some areas. Mineralization of water in the Ogallala in the northern Plains area varies with the thickness of saturation, the solubility of minerals in the underlying bedrock, and the presence of dune-sand cover. Water of better quality is found in the northeastern part of the area, where dune sand overlies the Ogallala and the saturated section is thick. Water of poorer quality is found along the western edge of the area and toward the south, where the saturation is thin. The highest mineralization is found in the southern part, where the Ogallala is underlain by Upper Cretaceous calcareous shale of the Niobrara Formation.

San Luis Valley -

Surface-water diversions from the Rio Grande and other streams have caused extensive waterlogging in the valley-fill material. The water table in about half of the San Luis Basin now lies within 6 feet of the land surface. Evapotranspiration losses estimated at some 2.4 billion cu m (2 million acre-ft) per year cause concentration of salts in the soil, and the shallow ground water has become highly mineralized. The total dissolved solids in 106 ground-water samples from the unconfined aquifer ranged from 72 to 29,900 mg/l with a median value of about 260 mg/l. 43) The least mineralized water in the shallow aquifer occurs on the west side of the valley.

The quality of water in the confined aquifer is somewhat better as far as dissolved solids is concerned. This aquifer is recharged by seepage from mountain streams flowing across the alluvial fan deposits at the edges of the valley floor. The concentration of dissolved solids of 93 samples from this aquifer ranged from 60 to 2,440 mg/l with a median value of about 200 mg/l. As discussed previously, the high fluoride content of the ground water is a problem over a large portion of the valley.

Western Colorado -

Water in the valley-fill deposits is generally hard and contains varying amounts of calcium, magnesium, bicarbonate, and sulfate. Irrigation water in the Upper Colorado River basin has a relatively low salt load (300 mg/l), and the evapotranspiration residue is relatively low. Solution pickup is high because of the large amount of crystalline salt in the soil and the shale bedrock. For this reason, the ground water in the sand and gravel deposits frequently is more mineralized than the river water, and in some irrigated areas the total dissolved solids are above 1,000 mg/l.

Ground-water quality in the bedrock formations is highly variable. In the Piceance Creek basin, recent studies show that the quality of ground water in the Green River Formation varies considerably from place to place. Near the edge of the basin, the total dissolved solids are less than 2,000 mg/l, but in the center they can be as much as 60,000 mg/l. Chloride concentrations in the center would be 1,000 mg/l or more. 46) Elsewhere in the region, dissolved solids commonly are less than 1,000 mg/l at depths less than 300 m (1,000 ft). Moderately saline or very saline water is common below 600 m (2,000 ft). 38)

The chemical quality of water in the Mesaverde Group is good to fair for domestic use, with dissolved solids in the range from 500 to 2,500 mg/l. Fluoride concentrations may exceed U. S. Public Health Service standards where dissolved solids concentrations are greater than 750 mg/l. Exploratory wells indicate that ground water with less than 3,000 mg/l dissolved solids extends to a depth of 1,200 m (4,000 ft). 38)

Water from the Dakota Sandstone east of Meeker generally contains less than 3,000 mg/l dissolved solids, ranging between 500 and 3,000 mg/l. Westward, dissolved solids concentrations exceed 3,000 mg/l in the Dakota Sandstone aquifer.

The chemical quality of the water in the Entrada, Glen Canyon, and Wingate Sandstones at shallow depths is good to excellent for domestic use (less than 500 mg/l dissolved solids). The quality of the ground water, however, deteriorates rapidly with depth and becomes very saline below 600 m (2,000 ft).

In the Mississippian limestone aquifer (Leadville Limestone) fresh water occurs near the outcrop and recharge areas, but below a depth of 300 m (1,000 ft) it appears to contain highly mineralized water. Springs discharge essentially fresh water, but in deep wells, concentrations of several thousand mg/l of dissolved solids are encountered, reflecting hydraulic connection with adjacent aquifers carrying water of a different type.

The quality of ground water in crystalline rocks of the highland area is good, and the dissolved solids content is low.

Idaho

The quality of ground water in Idaho is generally good, but there are local areas where aquifers contain water with high dissolved solids, sodium, and fluoride. The most prevalent problem is the presence of hard to very hard water. A compilation of chemical analyses of selected constituents in natural ground waters is given in Table 15.

Northern and Central Region -

In the Moscow Basin, water from both artesian and unconfined aquifers is moderately hard and contains excessively large amounts of iron and silica. Distribution of high concentrations of iron in ground water appears to be related to the occurrence of iron-rich clays in weathered rock within the recharge area on the east side of the basin. 54,55)

Ground water in the Salmon River basin is mainly obtained from valley-fill deposits and is of good quality. In the Pahsimeroi River basin, a tributary of the Salmon River, the ground water is moderately hard to hard with total dissolved solids between 100 and 300 mg/l. Ground water in the sedimentary and crystalline rocks of the upland areas is of good to excellent quality.

Snake River Basin -

In the Boise-Nampa area, ground water in the shallow aquifer is generally of good quality and suitable for most purposes. However, the dissolved solids in many areas exceeds the 250 mg/l recommended limit for drinking water set by the U. S. Public Health Service. Locally, the water may be quite hard, necessitating the use of water softeners. There is no apparent pattern to the distribution of dissolved minerals in the shallow aquifer. Water-quality information is not available for the deep aquifer.

In southern Canyon County, ground water from the Idaho Formation is generally of good quality, but in irrigated areas, unconsumed water infiltrating from canals and fields has caused increases in mineralization and nitrates. 48)

In Ada and Elmore Counties, locally high concentrations of

Table 15. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN IDAHO. Constituents in mg/l (milligrams per liter). 25, 47 through 53)

Location and Rock Type	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
	N	R	M	N	R	M	N	R	M
Southeast									
Alluvium	24	286 - 632	364	24	3 - 95	26	24	8 - 400	291
Snake Plain Aquifer	68	172 - 679 a)	334	119	6.5 - 325	21	36	109 - 440	226
NRTS Area									
Snake Plain Aquifer	69	153 - 583	209	69	6.0 - 160	10	69	94 - 368	158
Pahsimeroi River Basin									
Alluvium	7	92 - 345 a)	227	7	1.6 - 8.9	6.7	7	67 - 250	150
Southwest									
Alluvium	5	103 - 157	-	5	1.0 - 3.5	-	5	36 - 55	-
Snake Plain Aquifer	8	199 - 406	246	8	6.5 - 41	12	8	136 - 252	161
Idaho Formation	6	216 - 397	-	5	6 - 12	-	5	19 - 55	-
Boise-Nampa Area									
Shallow aquifers b)	5	98 - 667	-	64	0 - 48	5.6	5	53 - 306	-

N - Number of samples
R - Range
M - Median

a) Calculated

b) Shallow aquifers include the following hydraulically continuous beds: terrace gravels, Snake Group basalts, and Quaternary alluvium.

Table 15 Continued. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN IDAHO. Constituents in mg/l (milligrams per liter).[25, 47 through 53]

	Alkalinity (as $CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location and Rock Type	N	R	M	N	R	M	N	R	M
Southeast									
Alluvium	23	10 - 407	256	-	-	-	18	5.0 - 111	22
Snake Plain Aquifer	33	118 - 323	192	-	-	-	57	13 - 87	22
NRTS Area									
Snake Plain Aquifer	69	72 - 185	139	67	0.00 - 0.52	0.04	69	2.7 - 42	8.8
Pahsimeroi River Basin									
Alluvium	7	72 - 260	185	7	0 - 0.03	0.02	7	5.5 - 64	8.0
Southwest									
Alluvium	5	60 - 109	-	5	0.05 - 0.60	-	2	10 - 25	-
Snake Plain Aquifer	8	125 - 212	153	8	0.02 - 1.2	0.06	8	6.9 - 36	18
Idaho Formation	5	136 - 274	-	2	0 - 0.02	-	5	59 - 111	-
Boise-Nampa Area									
Shallow aquifers[b]	5	68 - 219	-	5	0.20 - 0.76	-	5	6.6 - 65	-

Table 15 Continued. TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN IDAHO. Constituents in mg/l (milligrams per liter). 25, 47 through 53)

Location and Rock Type	Sulfate (SO_4)			Nitrate (NO_3)			Fluoride (F)			pH		
	N	R	M	N	R	M	N	R	M	N	R	M
Southeast												
Alluvium	24	0 - 106	32	24	0.5 - 17	4.0	22	0 - 1.3	0.3	24	6.4 - 7.9	7.8
Snake Plain Aquifer	55	7 - 172	49	80	0 - 16	5.1	68	0.2 - 1.0	0.5	68	7.2 - 8.5	7.8
NRTS Area												
Snake Plain Aquifer	69	9.1 - 57	22	69	0.5 - 29	2.0	69	0 - 0.9	0.3	68	7.2 - 8.4	7.9
Pahsimeroi River Basin												
Alluvium	7	8.8 - 31	17	7	0.17 - 0.79	0.4	7	0 - 0.9	0.2	7	7.1 - 7.7	7.5
Southwest												
Alluvium	5	0.7 - 5.8	-	2	0.3 - 4.6	-	2	0.3 - 0.4	-	2	7.2 - 7.3	-
Snake Plain Aquifer	8	10 - 55	29	8	0.3 - 5.1	2.1	8	0.3 - 1.1	0.6	8	7.7 - 8.2	7.9
Idaho Formation	5	0.8 - 25	-	4	0.8 - 4	-	1	7	-	5	7.8 - 8.6	-
Boise-Nampa Area												
Shallow aquifers b)	5	2.0 - 148	-	128	0.1 - 58	9.4	5	0.3 - 0.5	-	37	6.7 - 7.9	7.2

total dissolved solids in ground water (600 to 1,200 mg/l) are found in places along the Snake River, due to irrigation returns. 56)

In the Bruneau-Grand View area, ground water contains excessive amounts of fluoride and is unsuitable for human consumption. Over 35 wells sampled in Owyhee County do not meet the U. S. Public Health Service drinking water standard for fluoride. 23) Average fluoride content of water was 10.6 mg/l. The fluoride is presumed to be derived from silicic volcanic rocks of the Idaho Formation. The amount of fluoride in basalt is relatively small, and elsewhere in Idaho ground water derived from basalt contains very little fluoride. 57) The artesian water also contains moderate to high amounts of sodium and is classified as marginal in quality for irrigation.

Ground water in the sand and gravel aquifers underlying the Camas Prairie area is of excellent quality. Total dissolved solids average about 150 mg/l, and the water is soft.

Ground water in the Big Wood-Silver Creek basin and the Big Lost River basin is of good quality, moderately hard to hard, and satisfactory for irrigation.

In the Mud Lake area, most of the ground water is satisfactory for all uses. In certain areas, ground water of poor quality exists as a result of concentrations of minerals from irrigation return flow.

In the Twin Falls area, water from the Snake River basalt is hard and contains large amounts of dissolved solids (400 to 1,300 mg/l); hardness as calcium carbonate averages about 400 mg/l. Marked differences in ground-water quality have been noted with changes in depth. The total dissolved solids concentration in the Twin Falls Tract changes from about 900 mg/l at a depth of 270 m (900 ft) to 350 mg/l at 370 m (1,200 ft), while the fluoride concentration increases from less than one mg/l to 6.8 mg/l. Water obtained at the 430 to 460 m (1,400 to 1,500 ft) depth was chemically different and of higher temperature. These changes in ground-water quality are indicative of complex hydrogeological conditions within the basalt aquifer. 58) Most of the ground water in the Twin Falls area is suitable for irrigation of selected crop types.

In the Salmon Falls area, serious ground-water quality problems exist. Ground water is hard to very hard, and is high in sulfates and total dissolved solids. High nitrates and boron are reported in some wells. Much ground water presents a medium to high salinity hazard for irrigation and is not suitable for human consumption. 59)

Ground water in the Raft River basin is very hard and somewhat high in chlorides and sodium. Some of the ground water has a medium to high salinity hazard. The average dissolved solids concentration of well and spring water is about 750 mg/l. Observed dissolved solids range from 120 to 3,200 mg/l within short distances, depending upon depth of wells and nearness to irrigated areas. 60) Ground water in Power and western Oneida Counties is generally of fair to poor quality. 61) The ground water in the Portneuf River basin is hard and generally contains less than 500 mg/l in total dissolved solids. 62)

Snake River Plain -

The chemical and bacteriological quality of ground water in the Snake Plain aquifer is generally good, and the water is suitable for most purposes. 52) The pattern of specific conductance values and areas irrigated by ground water are shown on Figure 29. Wells along the eastern and southern margins of the Plain generally yield water having a specific conductance greater than 300 micromhos/cm. The specific conductance of water in five irrigated areas exceeds 1,000 micromhos per centimeter. The specific conductance is less than 300 micromhos/cm in the central part of the Plain.

Chloride concentrations in the Snake Plain aquifer range from 7 to 325 mg/l, although in the heavily irrigated areas most concentrations range from 10 to 160 mg/l. Nitrate concentrations range from 2 to 32 mg/l, and have an areal distribution very similar to that of specific conductance and chloride. The distribution of the various dissolved constituents is complex, varying laterally and with depth in several areas. No well-defined seasonal trend in water quality exists.

A substantial amount of water-quality information is available for the NRTS (National Reactor Testing Station) and the surrounding area. A water sampling program has been carried out for 20 years using 45 observation wells. The quality of ground water is exceptionally good due to the abundant recharge from precipitation in the surrounding mountains, the high permeability of the aquifer, and the rapid underflow of most ground water. Total dissolved solids in ground water averages about 200 mg/l.

Recent hydrochemical studies have identified several distinctive types of ground water at the NRTS site. 63) Variations in chemical composition of ground waters beneath the eastern

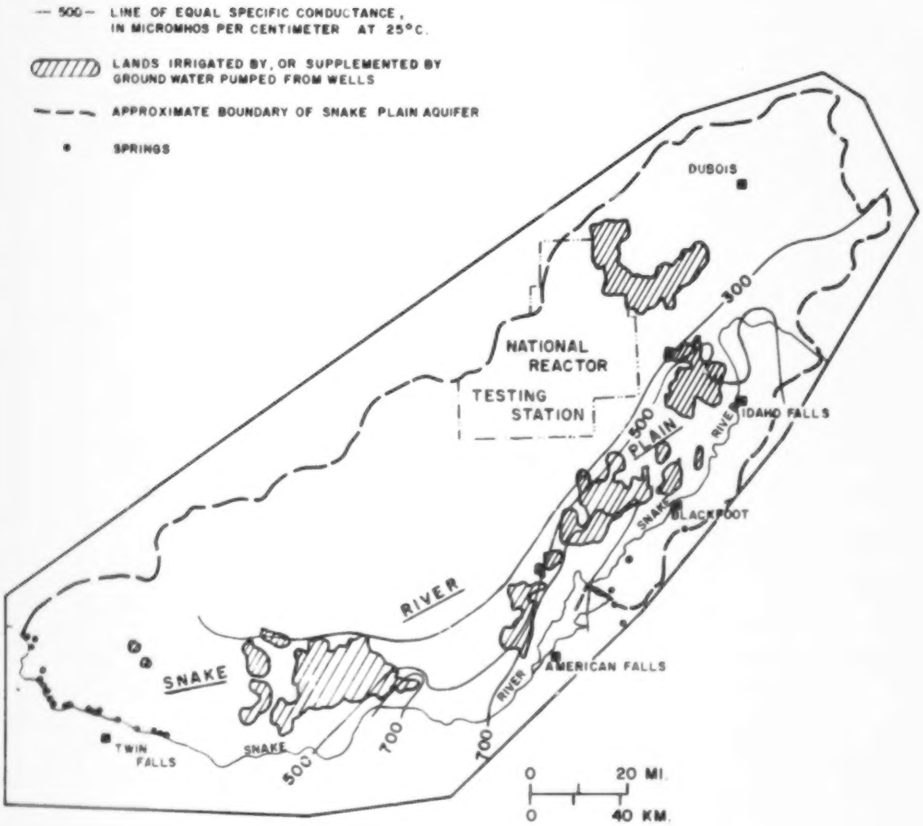
— 500 — LINE OF EQUAL SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25°C.
LANDS IRRIGATED BY, OR SUPPLEMENTED BY GROUND WATER PUMPED FROM WELLS
APPROXIMATE BOUNDARY OF SNAKE PLAIN AQUIFER
SPRINGS
DUBOIS
NATIONAL REACTOR TESTING STATION
300
500
PLAIN
IDAHO FALLS
SNAKE RIVER
BLACKFOOT
RIVER
SNAKE
AMERICAN FALLS
700
500
TWIN FALLS
SNAKE
0 20 MI.
0 40 KM.

Figure 29. Idaho - Conductivity of ground water in the Snake Plain Aquifer. 52)

Snake River Plain have made possible the identification of sources of recharge. Ground water relatively high in calcium, magnesium, and bicarbonate occurs beneath the northwest half of the NRTS. The composition of this water approximates the composition of surface water flowing southeast from the mountainous limestone and dolomite terrane northwest of the NRTS. Ground water beneath the southeastern half of the NRTS contains lower dissolved solids (175 to 200 mg/1) but greater concentrations of sodium, fluoride, and silica than ground water in the northwestern half. The ground water in the southeastern half of the NRTS is traced to a recharge area west of Yellowstone Park dominated by rhyolite and thermal water sources.

Little data is available regarding variation of water quality with depth in the Snake Plain aquifer. However, in one well drilled to a depth of 366 m (1,200 ft) at the NRTS site, significant increases were noted in sodium, fluoride, and silica concentrations with depth, possibly reflecting reaction of ground water with rhyolite.

Great Basin -

Ground-water quality in the Curlew Valley in Oneida County is fair to poor. The conductivity of the ground water ranges from 1,000 to 4,400 micromhos, and local high concentrations of chloride, sulfate, and nitrate occur. Elsewhere, the ground water in the Bear River basin is suitable for most purposes, although dissolved solids commonly exceed the 500 mg/1 recommended maximum. This is due, in part, to the presence of evaporite beds in the lake sediments. 51)

Montana

The quality of ground water is generally excellent to good in western Montana, excellent to fair in central Montana and good to poor in the eastern part of the state. Where sufficient recharge is available from precipitation or through induced infiltration from rivers and streams, the alluvial and valley-fill deposits yield water of good to excellent quality. Irrigation practices in many river valleys have resulted in waterlogging and serious ground-water quality problems. Poor water quality in some unconsolidated aquifers is due to upward movement of heavily mineralized artesian ground water. There is mounting concern about the growth of saline-alkali areas in northern Montana.

Ground-water quality in the bedrock aquifers varies greatly. In central and eastern Montana the water is fairly mineralized because the rocks contain greater amounts of soluble minerals. It is difficult, if not impossible, to find potable ground water here within U. S. Public Health Service recommended limits. Many community water-supply systems distribute very hard, mineralized water in absence of better quality water. Studies of the feasibility of desalting such municipal supplies have been made. 9) The extent and depth to saline ground water in the state is shown on Figure 30. The quality of ground water in principal unconsolidated and bedrock aquifers in various regions is described below. Table 16 is a compilation of chemical analyses of selected constituents in natural ground waters.

Unconsolidated Aquifers -

In the Bitterroot Valley, the quality of ground water in unconsolidated sediments of Recent and Tertiary age is generally excellent. The hardness of the ground water ranges from 17 to 210 mg/l, and the total dissolved solids concentration ranges from 40 to 750 mg/l. 81,92) Good quality of both surface and ground water is a contributing factor to successful irrigation projects and steady economic development in the valley. Even in waterlogged areas the quality of the water has not changed appreciably.

In the Kalispell Valley, water from the deep artesian aquifer is moderately hard (average total hardness 180 mg/l) and has a dissolved solids concentration ranging from 100 to 300 mg/l. It contains excessive amounts of iron and fluoride, frequently above U. S. Public Health Service standards for drinking water. 91) Commercial water softeners are used to alleviate water quality problems. The highly transmissive gravel aquifer underlying the floodplain is vulnerable to pollution from floodwaters and man-made causes. Water from this aquifer generally contains lower iron and dissolved solids concentrations than water from other aquifers. Hardness varies from 140 to 200 mg/l, and dissolved solids range from 130 to 210 mg/l. This variation in quality reflects the mixing of soft river water with ground water. Iron concentrations exceeding 2.0 mg/l are characteristic of the water in the sand aquifer. Water from perched dune and lacustrine aquifers is very hard and high in dissolved solids.

In the Gallatin Valley, ground water in the alluvial aquifer is mineralized to about 150 to 400 mg/l dissolved solids, is hard, and contains iron in excess of 0.3 mg/l. Water from underlying Tertiary deposits is more highly mineralized. 87)

In the Townsend Valley, the shallow alluvial aquifer contains hard and mineralized water. The average hardness is

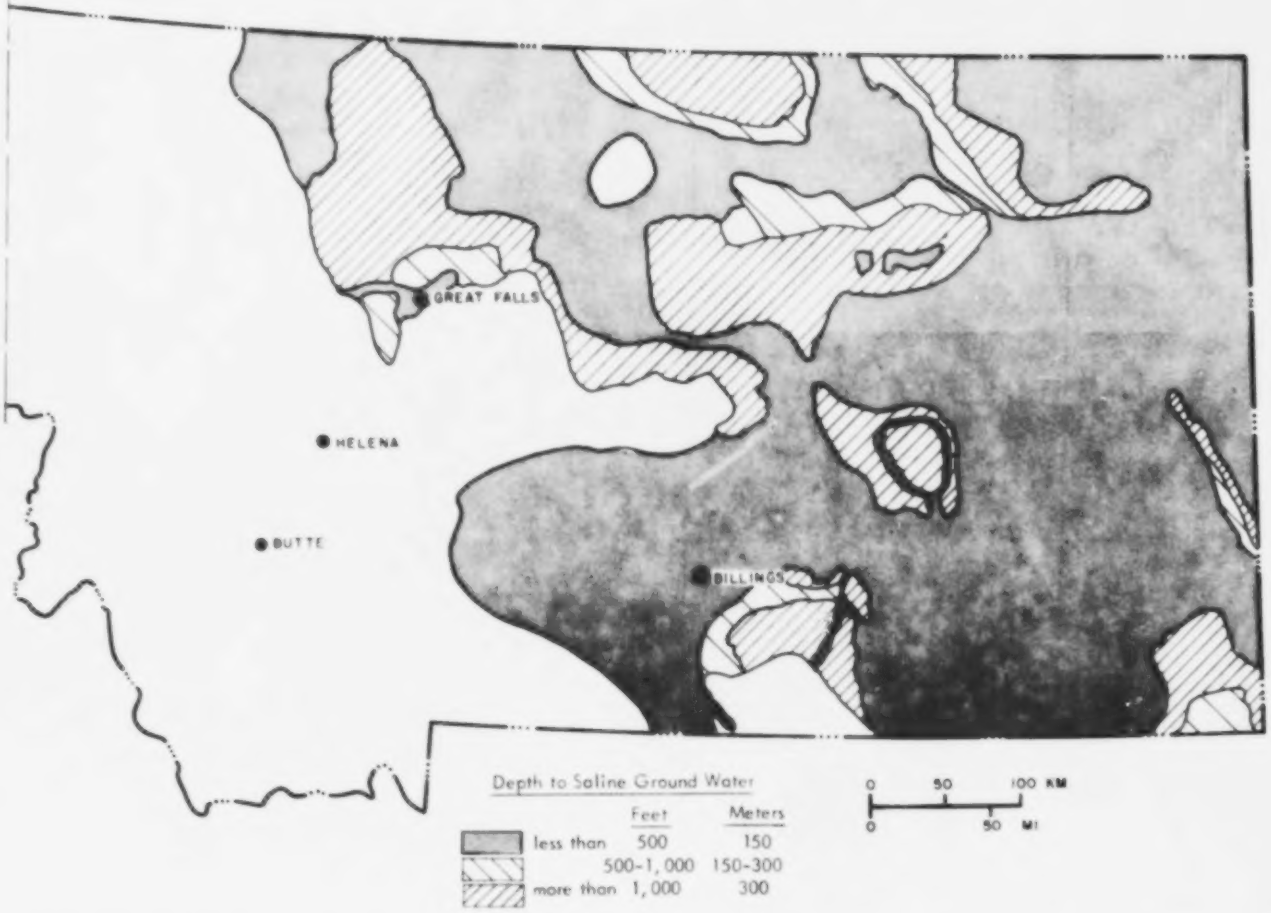
GREAT FALLS
HELENA
BUTTE
BILLINGS
Depth to Saline Ground Water
Feet
Meters
less than 500 150
500-1,000 150-300
more than 1,000 300
0 50 100 KM
0 50 MI

Figure 30. Montana - Depth to ground water containing more than 1,000 mg/l dissolved solids. 2)

Table 16 . TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg l (milligrams per liter), 64 through 92)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C) N	R	M	Chloride (Cl) N	R	M	Hardness (CaCO$_3$) N	R	M
Milk River Basin									
Alluvium	7	2,410 - 4,440	3,180	7	51 - 287	115	7	70 - 1,010	297
Judith River Formation	8	1,560 - 3,355 a)	1,890	5	4.7 - 221	-	7	10 - 68	16
Marias River Basin									
Alluvium	10	377 - 2,630	1,200	10	8.0 - 274	27	10	24 - 429	132
Eagle Sandstone	14	1,830 - 7,360	2,700	14	585 - 4,350	1,190	14	14 - 201	48
Missouri River Basin									
Alluvium	14	829 - 2,780	1,360	14	5.3 - 57	13	11	220 - 995	414
Fort Union Formation	19	1,120 - 5,340	2,040	19	4 - 52	21	3	42 - 67	-
Hell Creek Formation	13	1,000 - 5,250	2,790	13	4 - 32	11	1	167	-
Fox Hills Sandstone	21	550 - 3,920	1,870	21	0 - 35	21	-	-	-
Judith River Basin									
Alluvium	5	136 - 826	-	5	1 - 31	-	5	154 - 583	-
Eagle Sandstone	12	338 - 3,260	1,010	12	2.9 - 43	8	12	0 - 1,447	190
Colorado Shale	14	194 - 2,180	469	14	1.1 - 50	8	14	0 - 337	120
Kootenai Formation	31	148 - 810	389	31	0.8 - 12	4.5	28	10 - 490	183
Madison Group	7	200 - 3,359	372	7	3 - 26	4	6	152 - 1,370	-
Upper Yellowstone River Basin									
Livingston Formation	10	156 - 736	323	10	1 - 60	3.5	10	120 - 492	198

N - Number of samples
R - Range
M - Median

a) Sum
b) Calculated

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
	N	R	M	N	R	M	N	R	M
Lower Yellowstone and Powder River Basins									
Terrace Deposits	22	408 - 7,520	1,500	23	5.5 - 96	26	20	241 - 2,690	550
Hell Creek and Fort Union Formations	30	662 - 4,900	889	30	3.0 - 94	20	30	0 - 2,690	11
Fox Hills Sandstone and basal part of Hell Creek Formation	18	636 - 1,170	788	34	2.9 - 43	20	18	0 - 33	4
Bighorn River Basin									
Alluvium	18	400 - 7,720	1,240	19	2.0 - 148	9.5	28	260 - 2,650	616
Terrace Deposits	27	492 - 7,240	1,810	32	3.0 - 280	18	40	291 - 2,330	599
Marias River Basin									
Two Medicine Formation	13	504 - 3,440 b)	1,440	13	9 - 116	33	10	15 - 775	242
Eagle Sandstone	55	350 - 5,210 b)	1,160	52	7 - 3,200	26	39	5 - 2,450	230
Missouri River Basin									
Alluvium	5	175 - 8,546	-	5	0 - 630	-	5	20 - 2,264	-
Helena Valley									
Alluvium	15	162 - 514	254	15	0.0 - 47	5.0	15	90 - 336	171
Townsend Valley									
Alluvium	13	180 - 976	406	13	3.0 - 136	16	13	126 - 602	270
Tertiary Deposits	20	134 - 906	362	20	2.5 - 40	12	20	84 - 517	272

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C) N	R	M	Chloride (Cl) N	R	M	Hardness ($CaCO_3$) N	R	M
Gallatin River Valley									
Alluvium	20	154 - 398	242	22	0.5 - 8.5	2.0	22	114 - 312	198
Terrace Deposits	10	162 - 506	300	13	1.5 - 178	3.5	13	17 - 305	159
Bitterroot River Valley									
Alluvium	11	56 - 278	176	11	0.8 - 8.0	2.8	11	25 - 183	136
Clark Fork River Basin									
Quaternary Deposits	35	80 - 700	178	50	0.1 - 130	4.8	50	22 - 186	74
Granitic rocks of Boulder Batholith	4	158 - 244	-	6	2.4 - 6.9	-	6	49 - 109	-
Flathead River Basin									
Alluvium	12	132 - 1,480	210	12	2 - 250	4.5	12	135 - 755	200
Pleistocene artesian aquifers	27	116 - 848	214	27	1 - 52	3	27	51 - 430	204

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Milk River Basin									
Alluvium	7	477 - 845	750	7	0.4 - 9.4	5.0	5	685 - 1,250	-
Judith River Formation	8	599 - 1,451	1,040	5	0.00 - 2.2	-	7	609 - 940	656
Marias River Basin									
Alluvium	10	271 - 907	394	3	0.35 - 7.0	-	3	126 - 405	-
Eagle Sandstone	15	138 - 959	557	3	0.10 - 1.8	-	10	725 - 2,790	1,000
Missouri River Basin									
Alluvium	14	288 - 976	512	11	0.10 - 4.00	2.10	14	13 - 697	248
Fort Union Formation	19	420 - 1,719	726	3	0.02 - 0.05	-	19	109 - 1,490	660
Hell Creek Formation	13	460 - 1,214	776	1	0.68	-	13	331 - 1,520	807
Fox Hills Sandstone	21	315 - 1,163	705	-	-	-	21	78 - 1,130	547
Judith River Basin									
Alluvium	5	127 - 322	-	5	0 - 1.90	-	-	-	-
Eagle Sandstone	12	185 - 633	320	12	0.00 - 4.36	0.40	1	242	-
Colorado Shale	12	178 - 785	245	13	0.00 - 4.0	0	2	7.9 - 25	-
Kootenai Formation	31	5 - 412	230	28	0.00 - 23	0.24	3	28 - 159	-
Madison Group	7	95 - 235	160	4	0.0 - 0.34	-	-	-	-
Upper Yellowstone River Basin									
Livingston Formation	10	115 - 320	232	3	0.12 - 0.63	-	10	6.7 - 73	26

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Lower Yellowstone and Powder River Basins									
Terrace Deposits	24	218 - 640	472	20	0.06 - 6.9	40	24	46 - 1,790	314
Hell Creek and Fort Union Formations	29	308 - 1,599	656	30	0.00 - 25.40	0.10	16	106 - 733	336
Fox Hills Sandstone and basal part of Hell Creek Formation	34	360 - 1,169	616	18	0.00 - 2.10	0.00	21	247 - 877	421
Bighorn River Basin									
Alluvium	28	183 - 562	395	12	0.21 - 3.9	1.55	27	18 - 1,300	262
Terrace Deposits	40	216 - 951	346	22	0.07 - 5.5	0.18	38	34 - 1,380	194
Marias River Basin									
Two Medicine Formation	13	280 - 869	581	10	0.00 - 18.4	0.52	-	-	-
Eagle Sandstone	53	185 - 725	476	43	0.00 - 19.0	0.22	-	-	-
Missouri River Basin									
Alluvium	5	133 - 445	-	5	0.0 - 0.7	-	-	-	-
Helena Valley									
Alluvium	15	71 - 254	143	15	0.00 - 4.4	0.04	15	12 - 34	17
Townsend Valley									
Alluvium	13	120 - 379	222	13	0.02 - 1.5	0.10	13	8.2 - 61	32
Tertiary Deposits	20	85 - 344	169	20	0.02 - 10	0.18	20	6.0 - 84	22

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Gallatin River Valley									
Alluvium	22	121 - 274	189	15	0.02 - 2.6	0.38	22	2.1 - 20	5.7
Terrace Deposits	13	92 - 279	202	7	0.07 - 4.2	1.2	13	4.0 - 187	26
Bitterroot River Valley									
Alluvium	11	36 - 211	140	11	0.00 - 4.1	0.16	7	3.0 - 24	8.6
Clark Fork River Basin									
Quaternary Deposits	50	22 - 186	75	5	0.02 - 0.15	-	49	2.6 - 50	10.5
Granitic rocks of Boulder Batholith	6	48 - 108	-	-	-	-	6	6.2 - 15.3	-
Flathead River Basin									
Alluvium	12	145 - 574	189	12	0 - 14.12	0.07	-	-	-
Pleistocene artesian aquifers	27	110 - 698	222	27	0 - 3.8	0.10	-	-	-

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Sulfate (SO_4)			Nitrate (NO_3)			Fluoride (F)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Milk River Basin									
Alluvium	7	978 - 2,320	1,390	5	3.0 - 7.6	-	5	0.6 - 1.6	-
Judith River Formation	8	279 - 1,770	840	5	0.0 - 5.2	-	8	2.0 - 4.5	3.2
Marias River Basin									
Alluvium	10	6.2 - 1,100	281	10	0.0 - 96	3.0	10	0.2 - 2.8	1.3
Eagle Sandstone	14	3.1 - 72	8.4	11	0.0 - 1.5	0.8	14	0.7 - 3.0	1.6
Missouri River Basin									
Alluvium	14	58 - 1,270	516	11	0.5 - 100	4.0	11	0.0 - 0.8	0.5
Fort Union Formation	19	6.8 - 2,400	692	3	0.0 - 2.5	-	3	1.4 - 3.2	-
Hell Creek Formation	13	157 - 2,250	985	1	2.5	-	1	1.0	-
Fox Hills Sandstone	20	10 - 1,730	556	-	-	-	-	-	-
Judith River Basin									
Alluvium	5	8 - 387	-	4	0.2 - 120	-	4	0 - 0.8	-
Eagle Sandstone	12	55 - 1,956	342	11	0.0 - 45	1.2	12	0.2 - 1.1	0.6
Colorado Shale	14	2.6 - 910	116	11	0.0 - 59	0	11	0.24 - 4.8	0.8
Kootenai Formation	31	2.5 - 475	60	26	0.0 - 35	0	25	0 - 2.4	0.7
Madison Group	7	10 - 2,339	162	4	0.0 - 62	-	4	0.1 - 0.5	-
Upper Yellowstone River Basin									
Livingston Formation	10	8.5 - 223	38	10	0.4 - 27.0	3.4	9	0.1 - 0.7	0.2

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg l (milligrams per liter). 64 through 92)

Location - Aquifer	Sulfate (SO$_4$)			Nitrate (NO$_3$)			Fluoride (F)		
	N	R	M	N	R	M	N	R	M
Lower Yellowstone and Powder River Basins									
Terrace Deposits	24	102 - 4,860	640	24	0.5 - 115	5.6	24	0.2 - 1.5	0.6
Hell Creek and Fort Union Formations	30	2.4 - 3,140	62	30	0.0 - 115	0.5	30	0.0 - 6.0	1.8
Fox Hills Sandstone and basal part of Hell Creek Formation	34	15 - 942	123	18	0.0 - 0.2	0.0	18	0.6 - 2.5	1.4
Bighorn River Basin									
Alluvium	19	28 - 4,630	420	19	0.0 - 3.8	0.3	18	0.1 - 0.7	0.3
Terrace Deposits	32	106 - 4,400	808	31	0.0 - 122	3.3	28	0.1 - 0.8	0.5
Marias River Basin									
Two Medicine Formation	13	97 - 1,950	436	10	0.0 - 10.6	0.2	10	0.4 - 7.5	1.2
Eagle Sandstone	53	10 - 3,090	437	34	0.0 - 269	0.9	37	0.0 - 3.7	0.8
Missouri River Basin									
Alluvium	5	25 - 4,790	-	5	0 - 2.3	-	5	0.2 - 2.4	-
Helena Valley									
Alluvium	15	12 - 146	67	15	0.2 - 34	2.7	15	0.2 - 1.5	0.4
Townsend Valley									
Alluvium	13	17 - 204	66	13	0.2 - 364	4.4	9	0.0 - 1.2	0.2
Tertiary Deposits	20	14 - 308	86	20	0.4 - 86	4.5	20	0.0 - 1.2	0.3

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Sulfate (SO_4)			Nitrate (NO_3)			Fluoride (F)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Gallatin River Valley									
Alluvium	22	0.0 - 64	20	22	0.7 - 16	2.8	22	0.0 - 0.5	0.1
Terrace Deposits	13	1.0 - 116	31	13	0.4 - 24	2.7	13	0.0 - 11	0.4
Bitterroot River Valley									
Alluvium	11	1.6 - 24	5.1	10	0.0 - 19	3.2	10	0.0 - 0.3	0.2
Clark Fork River Basin									
Quaternary Deposits	50	4 - 269	36	5	0.0 - 1.4	-	5	0.0	-
Granitic rocks of Boulder Batholith	6	22 - 70	-	-	-	-	-	-	-
Flathead River Basin									
Alluvium	12	2 - 200	6.5	12	0 - 208	1.2	12	0 - 0.6	0.1
Pleistocene artesian aquifers	27	0 - 20	5	27	0 - 5.3	0	27	0 - 4.4	0

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). (4 through 92)

	Silica (SiO_2)			pH		
Location - Aquifer	N	R	M	N	R	M
Milk River Basin						
Alluvium	7	7.5 - 144	19	5	7.3 - 7.8	-
Judith River Formation	2	10	-	7	7.6 - 9.0	8.4
Marias River Basin						
Alluvium	3	17 - 23	-	10	7.5 - 8.7	8.2
Eagle Sandstone	10	6.3 - 18	13	14	8.0 - 9.5	8.2
Missouri River Basin						
Alluvium	11	11 - 26	16	14	7.1 - 8.4	7.8
Fort Union Formation	3	7.0 - 12	-	18	7.4 - 8.7	8.1
Hell Creek Formation	1	8.0	-	12	7.3 - 8.4	8.0
Fox Hills Sandstone	-	-	-	17	7.6 - 8.5	8.1
Judith River Basin						
Alluvium	1	15	-	-	-	-
Eagle Sandstone	2	3.3 - 23	-	1	7.9	-
Colorado Shale	3	3.5 - 14.6	-	2	7.6 - 8.4	-
Kootenai Formation	6	0 - 11	-	2	8.2	-
Madison Group	2	7.2 - 10.2	-	-	-	-
Upper Yellowstone River Basin						
Livingston Formation	10	7.8 - 21	12	10	7.5 - 8.0	7.8

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

	Silica (SiO_2)			pH		
Location - Aquifer	N	R	M	N	R	M
Lower Yellowstone and Powder River Basins						
Terrace Deposits	24	9.8 - 31	22	24	7.2 - 8.1	7.7
Hell Creek and Fort Union Formations	19	6.3 - 28	12	19	7.8 - 9.0	8.6
Fox Hills Sandstone and basal part of Hell Creek Formation	[illegible]	11 - 14	-	21	7.6 - 9.0	8.4
Bighorn River Basin						
Alluvium	19	10 - 25	17	27	7.2 - 8.3	7.4
Terrace Deposits	32	12 - 30	24	36	7.0 - 8.1	7.5
Marias River Basin						
vo Medicine Formation	-	-	-	-	-	-
Eagle Sandstone	-	-	-	-	-	-
Missouri River Basin						
Alluvium	-	-	-	-	-	-
Helena Valley						
Alluvium	15	13 - 33	22	15	7.0 - 8.4	7.5
Townsend Valley						
Alluvium	13	16 - 50	25	13	7.2 - 7.8	7.4
Tertiary Deposits	20	9.9 - 38	21	20	7.1 - 8.0	7.6

Table 16 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN MONTANA. Concentrations in mg/l (milligrams per liter). 64 through 92)

Location - Aquifer	Silica (SiO_2)			pH		
	N	R	M	N	R	M
Gallatin River Valley						
Alluvium	22	4.6 - 38	22	22	7.3 - 8.2	7.6
Terrace Deposits	13	7.0 - 61	30	13	7.5 - 8.6	7.9
Bitterroot River Valley						
Alluvium	9	13 - 36	17	8	6.7 - 7.7	7.3
Clark Fork River Basin						
Quaternary Deposits	5	4.0 - 9.8	-	50	4.7 - 8.2	7.1
Granitic rocks of Boulder Batholith	-	-	-	6	6.8 - 8.0	-
Flathead River Basin						
Alluvium	-	-	-	-	-	-
Pleistocene artesian aquifers	-	-	-	-	-	-

270 mg/l, and the total dissolved solids are 400 mg/l. The salinity and hardness of the shallow ground water is greater in the irrigated areas of the valley. Locally, excessive concentrations of iron and nitrate occur in the shallow aquifer. 86)

In the Helena Valley, ground water in the alluvium and in the Tertiary lake deposits is quite similar in chemical quality. The total dissolved solids average 250 mg/l, and the total hardness ranges from 100 to 300 mg/l. Evaporation of ground water in the waterlogged area has resulted in increased salinity in soil and ground water. 85)

South of the city of Butte, ground water in the alluvial valley fill is generally of good quality. The total dissolved solids range between 100 and 300 mg/l. Silver Bow Creek, which drains the area, is severely polluted, and the ground-water quality near this stream is poorer than in other areas sampled. 90) This poor quality may reflect ground-water seepage from mineralized zones. There are some 800 ha (2,000 acres) of waterlogged land in the valley.

In the White Sulphur Springs area, water from the alluvial aquifer is hard (180 to 280 mg/l). Some water is high in dissolved solids (2,000 to 3,000 mg/l) and of limited suitability for irrigation. 72)

In central and eastern Montana, ground water from the unconsolidated aquifers is of variable quality. Water in permeable glacial deposits such as kames, eskers, and outwash channels is generally good to excellent. Water in glacial till in north-central and northeastern Montana is generally poor. Ground water in the unconsolidated aquifers is affected by the poor quality water in the surrounding shale bedrock aquifer. The bedrock contains a large amount of soluble minerals, and with limited recharge, the slow movement of ground water causes more mineralization to take place. In the Big Sandy-Laredo area, ground water from Quaternary deposits is relatively high in total dissolved solids (400 to 2,600 mg/l) and sulfates (300 to 900 mg/l), but this water is of better quality than that in the underlying bedrock. 19)

In the Milk River valley in Blaine County, the quality of the water from the alluvial deposits ranges from excellent to unusable; many wells have been abandoned because of the alkalinity of their water. 70)

In the Missouri River valley, downstream of the Fort Peck Reservoir to the North Dakota state line, the water in the alluvial aquifers is of poor quality. It is highly mineralized and hard. The dissolved solids range from 800 to 2,800 mg/l, and the hardness ranges from 200 to 1,000 mg/l. In addition, the iron content is over one mg/l, and sulfate is over 250 mg/l. The poor chemical quality of the water appears to be due to the concentration of constituents by evaporation and transpiration. 19) Many towns are utilizing highly mineralized water from municipal supplies in the absence of better quality water. For example, at Wolf Point, the municipal water system uses water from the Missouri River alluvium that is highly mineralized (1,000 to 1,700 mg/l total dissolved solids) and contains excessive iron (up to 4.6 mg/l). The underlying bedrock aquifers also contain highly mineralized water (total dissolved solids 1,000 to 4,400 mg/l). Surface water in the Missouri River is hard, contains 270 to 460 mg/l dissolved solids, and receives irrigation return water and untreated industrial waste. 9)

The Flaxville Formation of Tertiary age, underlying some 40,000 ha (100,000 acres) in northern Blaine County, has relatively good quality water which is suited for irrigation and drinking. Dissolved solids concentrations range from 350 to 1,500 mg/l in comparison with concentrations of 1,000 to 4,000 mg/l for other aquifers in the area. 67)

The alluvium in the Musselshell River valley contains highly mineralized water in places. In Musselshell and Golden Valley Counties, the water is very hard, containing over 1,000 mg/l total dissolved solids, and is high in sulfates. 71)

The water quality of the alluvial deposits in the Yellowstone River valley appears to deteriorate in a downstream direction. It varies widely from acceptable to highly mineralized. Waterlogging of irrigated land on terraces causes further deterioration of water quality. 75,76) In the vicinity of Billings, ground water is too highly mineralized to be used for drinking, but the water appears to be adequate for livestock. The best ground-water supply in the area contains 300 to 800 mg/l dissolved solids. Most ground water contains very high concentrations of sulfate and sodium. 93)

In the lower Bighorn Valley, alluvial gravel deposits are covered by clay beds that act as confining zones, and ground water in the alluvium in the irrigated lowlands is under artesian pressure. Capillary rise and evapotranspiration in waterlogged areas has produced harmful alkali deposits. Concentrations of total dissolved solids in alluvial ground water range from 600 to 7,000 mg/l. 79) In the Lower Little Bighorn River valley, ground water from the unconsolidated deposits is generally unsuitable for irrigation and domestic use, and in places the dissolved solids exceed 4,000 mg/l. 80)

Bedrock Aquifers -

In western Montana, the quality of ground water in bedrock aquifers is generally good. The crystalline rocks of the Belt Series and intrusive rocks are dense and hard and do not contain readily soluble minerals. In eastern Montana, however, the sedimentary rocks contain soluble minerals, and the ground water has become mineralized in many areas. The chemical quality varies greatly from region to region and even with depth in the same aquifer. For example, water quality in a given aquifer may be quite acceptable in the outcrop and recharge area, but away from the recharge area it may deteriorate rapidly. Sandstone aquifers that are overlain by shale containing large amounts of soluble minerals often contain poorer quality water than sandstone exposed at the land surface. When covered by low permeability shales, such sandstones receive an inadequate volume of recharge to improve the quality of the water.

In the outcrop area of the Fort Union Formation, most water wells yield fair to good quality water. In Yellowstone County, the total dissolved solids range from 300 to 1,500 mg/l. In Roosevelt and Sheridan Counties in northeastern Montana, the water from depths greater than 30 m (100 ft) is soft, but moderately to strongly mineralized. Water from lignite beds is nonpotable. In Valley County, the ground water is low in dissolved solids concentration but high in sodium content. 94)

Sandstones in the Hell Creek Formation in Yellowstone County yield water with an average total dissolved solids of 1,000 mg/l. The Hell Creek-Fox Hills aquifer near Terry and on the western flank of the Cedar Creek anticline yields soft water, but the water is strong in sodium bicarbonate and not suited for irrigation. 77,78) The quality of water from the Two Medicine Formation ranges from good to unusable for domestic purposes in the Cut Bank area. Water from the Judith River Formation in northern Hill County and in north-central Montana is too mineralized for domestic use. In the latter area, the water contains 1,500 to 3,000 mg/l dissolved solids, 500 to 1,700 mg/l sulfate, and 2.0 to 3.5 mg/l fluoride. 93)

Sandstone of the Eagle Formation supplies good to fair quality water in the Cut Bank area, in the Judith River basin, and in Joliet and Carbon Counties. However, in northern Hill County, a sandstone well 520 m (1,700 ft) deep produces strongly mineralized water unfit for drinking. On the Fort Belknap Indian Reservation, water in the Virgelle Sandstone is of fair to poor quality, as the water contains moderate to large concentrations of sulfate and iron. 69) Aquifers in the Kootenai Formation yield good to fair quality water. Excessive sodium makes the water unsuitable for irrigation in Big Horn County.

The quality of water from the Madison Limestone is highly variable. In the Judith River basin and in Cascade County, water in the upper zone of the aquifer is of good quality; however, at depth, it is more mineralized. In the Cut Bank area, the Madison yields water with a dissolved solids content greater than 7,000 mg/l. In Big Horn County, the Madison Limestone yields low-salinity water from a depth of 1,200 m (4,000 ft) that is suitable for irrigation but not potable because of its calcium content. In the Bluewater Springs area of Carbon County, the dissolved solids of Madison water from a depth of 380 m (1,250 ft) ranges from 1,000 to 1,500 mg/l. 74)

The Amsden, Tensleep, and Chugwater Formations contain aquifers that locally yield good to fair quality water. Water in the Tensleep Sandstone in Carbon County has dissolved solids ranging from 1,000 to 2,500 mg/l. 74)

Oregon

The ground water in Oregon is of good to excellent quality. However, there are local problems of excessive iron, fluoride, arsenic, and dissolved solids as well as excessive hardness. Most of the information on ground-water quality is for the Willamette Valley, where two-thirds of the state's population is concentrated and ground water is heavily utilized. Less data are available for the remainder of the state. The quality of ground water in each region is discussed below. A compilation of chemical analyses of selected constituents in natural ground waters is shown in Table 17.

Willamette Valley -

Water in the unconsolidated deposits is of good quality for most purposes. It is fairly low in dissolved solids (100 to 150 mg/l) and has a hardness of 30 to 150 mg/l. In contrast, connate ground water from the consolidated sedimentary rocks below the valley-fill deposits is commonly very hard (greater than 180 mg/l) and saline. 95) In the southern Willamette Valley, the sand and gravel aquifer in the Eugene-Springfield area contains water with dissolved solids of 100 to 200 mg/l and a hardness of 20 to 130 mg/l. In contrast, the sandstone aquifer typically yields water with total dissolved solids in the 500 to 700 mg/l range and a total hardness of 400 to 600

Table 17 . TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C) N	R	M	Chloride (Cl) N	R	M	Hardness (CaCO$_3$) N	R	M
Northern Willamette Basin									
Alluvium	21	26 - 230	134	21	1.8 - 32	5.5	21	9.5 - 151	65
Columbia River Group basalt	13	162 - 752	212	19	3.5 - 11,600	22	19	29 - 1,100	128
Tualatin Valley									
Alluvium	9	100 - 780	278	10	2.1 - 350	8.2	10	36 - 293	84
Columbia River Group basalt	11	99 - 3,640	224 a)	12	1.5 - 1,840	22	12	34 - 1,480	113
Portland Area									
Alluvium	12	130 - 454	154	12	2 - 156	6	12	34 - 163	78
Columbia River Group basalt	6	126 - 918	-	9	3.2 - 356	136	9	14 - 312	107
French Prairie Area									
Alluvium	4	132 - 186	-	6	0.0 - 26	-	6	37 - 121	-
Troutdale Formation	14	123 - 276	182	14	2.2 - 23	3.0	14	68 - 146	110
Molalla-Salem Slope Area									
Troutdale Formation	6	61 - 195	- b)	6	2.0 - 6.5	-	6	22 - 124	-

N - Number of samples
R - Range
M - Median
a) - Total Dissolved Solids
b) - Calculated

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg l (milligrams per liter). 7, 8, 16, 97 through 112)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C) N	R	M	Chloride (Cl) N	R	M	Hardness (CaCO$_3$) N	R	M
Southern Willamette Basin									
Eugene-Springfield Area									
Alluvium	8	24 - 382	155	5	1.5 - 114	-	10	20 - 130	46
Corvallis-Albany Area									
Alluvium and Terrace Deposits	19	114 - 1,060	210 b)	19	2.5 - 590	13	19	38 - 610	102
Lane County									
Fisher Formation and correlative rocks	5	73 - 4,360	- b)	5	1.5 - 2,100	-	5	10 - 1,320	-
Coastal Belt - Coos Bay Area									
Sand	3	68 - 162	-	7	10 - 33	18	7	16 - 97	18
Rogue River Basin - Medford-Ashland Area									
Alluvium	10	160 - 710	280 a)	10	4.2 - 282	13	15	23 - 288	170
Non-marine Sedimentary Rocks	32	165 - 3,400	405	42	1.5 - 2,020	22	50	4 - 1,020	190
Deschutes River Basin									
Alluvium and Fluviolacustrine Deposits	13	136 - 371	254	21	2.8 - 20	4.2	21	61 - 238	90

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). (7, 8, 16, 97 through 112)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness (CaCO$_3$)		
	N	R	M	N	R	M	N	R	M
Umatilla River Basin									
Columbia River Group basalt	55	114 - 561	253	73	1.8 - 192	14	72	5 - 334	84
Grande Ronde River Basin									
Alluvium	12	75 - 246	166	12	0.2 - 10	1.4	12	20 - 130	92
Columbia River Group basalt	3	111 - 461	-	7	0.8 - 129	2.1	7	10 - 28	18
Burnt River Valley									
Alluvium and Fluviolacustrine Deposits	-	-	-	7	2.8 - 49	12	7	6 - 720	200

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Northern Willamette Basin									
Alluvium	21	4 - 158	69	21	0.02 - 2.13	0.12	21	2.2 - 38	7.0
Columbia River Group basalt	18	11 - 204	127	18	0.02 - 1.2	0.16	7	8.3 - 2,350	39
Tualatin Valley									
Alluvium	11	58 - 351	151	7	0.01 - 0.8	0.1	4	8.9 - 98	-
Columbia River Group basalt	11	51 - 150	128	10	0.03 - 5.1	0.12	6	7.7 - 290	-
Portland Area									
Alluvium	10	44 - 189	95	11	0.01 - 1.8	0.06	10	4.4 - 79	8.7
Columbia River Group basalt	9	57 - 122	95	8	0.06 - 0.4	0.14	3	7 - 10	-
French Prairie Area									
Alluvium	6	47 - 130	-	6	0.06 - 4.0	-	4	3.5 - 26	-
Troutdale Formation	14	72 - 198	130	14	0.20 - 5.3	0.94	14	5.6 - 71	8.8
Molalla-Salem Slope Area									
Troutdale Formation	6	33 - 136	-	6	0.19 - 2.2	-	6	5.1 - 25	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Southern Willamette Basin									
Eugene-Springfield Area									
Alluvium	6	60 - 100	-	8	0 - 0.65	0.10	5	7.4 - 64	-
Corvallis-Albany Area									
Alluvium and Terrace Deposits	16	56 - 266	96	19	0.01 - 13.4	0.04	18	5.9 - 280	15
Lane County									
Fisher Formation and correlative rocks	5	30 - 259	-	4	0.04 - 0.38	-	5	6.1 - 810	-
Coastal Belt - Coos Bay Area									
Sand	7	6 - 23	11	4	0.36 - 2.5	-	3	8.3 - 11.5	-
Rogue River Basin - Medford-Ashland Area									
Alluvium	15	79 - 303	179	10	0.02 - 19	0.06	10	9.3 - 154	23
Non-marine Sedimentary Rocks	49	44 - 2,800	225	33	0.00 - 13	0.03	42	8.5 - 1,800	62
Deschutes River Basin									
Alluvium and Fluviolacustrine Deposits	13	103 - 280	148	20	0.0 - 0.57	0.04	-	-	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Umatilla River Basin									
Columbia River Group basalt	26	53 - 212	141	53	0.00 - 16.5	0.07	66	6.1 - 133	34
Grande Ronde River Basin									
Alluvium	12	29 - 171	88	7	0.00 - 0.27	0.09	12	2.2 - 28	9.5
Columbia River Group basalt	3	59 - 69	-	5	0.00 - 0.04	-	7	15 - 128	27
Burnt River Valley									
Alluvium and Fluviolacustrine Deposits	7	78 - 943	336	-	-	-	7	14 - 397	49

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	Sulfate (SO_4)			Nitrate (NO_3)			Silica (SiO_2)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Northern Willamette Basin									
Alluvium	21	2.1 - 10	4.2	21	0.05 - 16	3.6	21	8.8 - 60	41
Columbia River Group basalt	19	0.6 - 64	9.8	6	0.05 - 0.5	-	17	30 - 95	47
Tualatin Valley									
Alluvium	5	0 - 0.8	-	2	0.1 - 0.3	-	6	13 - 46	-
Columbia River Group basalt	10	0.6 - 25	2.4	7	0.1 - 1.5	0.1	10	26 - 55	44
Portland Area									
Alluvium	11	1.6 - 20	4.8	9	0 - 15	0.4	11	40 - 64	45
Columbia River Group basalt	8	0.3 - 13	1.2	3	0.0 - 3.5	-	8	24 - 60	52
French Prairie Area									
Alluvium	6	2.5 - 13	-	6	0.0 - 43	-	6	19 - 54	-
Troutdale Formation	14	0.2 - 8.0	2.8	14	0.0 - 24	0.1	14	20 - 64	46
Molalla-Salem Slope Area									
Troutdale Formation	6	0.0 - 1.6	-	6	0.0 - 0.2	-	6	25 - 48	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). [7, 8, 16, 97 through 112]

	Sulfate (SO_4)			Nitrate (NO_3)			Silica (SiO_2)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Southern Willamette Basin									
Eugene-Springfield Area									
Alluvium	8	0 - 21	2.2	6	0.0 - 26	-	8	9.5 - 43	26
Corvallis-Albany Area									
Alluvium and Terrace Deposits	18	0 - 26	6.4	7	0 - 7.4	1.2	17	20 - 61	42
Lane County									
Fisher Formation and correlative rocks	5	0.4 - 10	-	5	0.0 - 9.3	-	5	10 - 40	-
Coastal Belt - Coos Bay Area									
Sand	3	0.4 - 3.0	-	3	0.0 - 1.4	-	3	19 - 23	-
Rogue River Basin - Medford - Ashland Area									
Alluvium	10	1.1 - 52	6	10	0.0 - 41	2.0	10	19 - 60	34
Non-marine Sedimentary Rocks	41	0.4 - 205	17	41	0.0 - 36	1.4	43	10 - 81	24
Deschutes River Basin									
Alluvium and Fluviolacustrine Deposits	13	4.0 - 55	15	6	0.1 - 10	-	2	37 - 51	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	Sulfate (SO_4)			Nitrate (NO_3)			Silica (SiO_2)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Umatilla River Basin									
Columbia River Group basalt	72	0.0 - 120	11	45	0.0 - 57	0.1	66	20 - 79	57
Grande Ronde River Basin									
Alluvium	8	0.3 - 23	2.0	12	0.1 - 49	1.1	12	34 - 51	42
Columbia River Group basalt	7	3.3 - 56	4.5	5	0.0 - 0.2	-	7	38 - 88	72
Burnt River Valley									
Alluvium and Fluviolacustrine Deposits	7	1.4 - 135	59	7	0.0 - 205	0.0	-	-	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

	pH		
Location - Aquifer	N	R	M
Northern Willamette Basin			
Alluvium	-	-	-
Columbia River Group basalt	18	6.2 - 8.3	7.4
Tualatin Valley			
Alluvium	7	6.5 - 7.6	7.2
Columbia River Group basalt	11	6.8 - 8.2	7.4
Portland Area			
Alluvium	9	6.5 - 8.0	7.4
Columbia River Group basalt	9	6.8 - 8.6	7.8
French Prairie Area			
Alluvium	3	6.6 - 6.8	-
Troutdale Formation	11	6.7 - 8.0	7.7
Molalla-Salem Slope Area			
Troutdale Formation	6	6.5 - 7.6	-

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter). 7, 8, 16, 97 through 112)

		pH	
Location - Aquifer	N	R	M
Southern Willamette Basin			
Eugene-Springfield Area			
Alluvium	8	6.8 - 8.1	7.4
Corvallis-Albany Area			
Alluvium and Terrace Deposits	18	6.3 - 7.8	7.2
Lane County			
Fisher Formation and correlative rocks	4	7.2 - 8.6	-
Coastal Belt - Coos Bay Area			
Sand	7	5.9 - 7.8	-
Rogue River Basin - Medford-Ashland Area			
Alluvium	15	6.8 - 8.2	7.6
Non-marine Sedimentary Rocks	50	7.1 - 9.3	7.8
Deschutes River Basin			
Alluvium and Fluviolacustrine Deposits	7	7.1 - 8.0	7.6

Table 17 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN OREGON. Concentrations in mg/l (milligrams per liter).[7, 8, 16, 97 through 112)]

		pH	
Location - Aquifer	N	R	M
Umatilla River Basin			
Columbia River Group basalt	72	6.5 - 8.7	8.0
Grande Ronde River Basin			
Alluvium	12	6.6 - 8.0	7.2
Columbia River Group basalt	6	7.4 - 9.5	-
Burnt River Valley			
Alluvium and Fluviolacustrine Deposits	7	7.0 - 9.4	7.5

mg/l. 101) Elsewhere in the valley, considerably more saline ground water (up to 18,500 mg/l dissolved solids) has been encountered in the bedrock formations. The occurrence of high arsenic concentrations in ground water in Lane County was discussed previously.

In the central and northern part of the valley, the ground water is generally of excellent quality and suitable for public supply and most industrial uses. In the Molalla-Salem Slope area, iron and manganese concentrations are excessive. Iron and manganese in water from the Troutdale Formation ranges from 0.19 to 2.2 mg/l and averages 0.86 mg/l. Ground water in the Columbia River Group basalt averaged 0.72 mg/l, and water from the marine rocks averaged 1.12 mg/l of iron. 100,102) The extent of the area where iron in ground water may exceed 0.35 mg/l is shown on Figure 31.

In the French Prairie area, a highly productive agricultural region in the northern Willamette Valley, the quality of ground water from the nonmarine sedimentary rocks is generally good. The ground water is low in dissolved solids but contains excessive iron (over 0.3 mg/l). Silica, derived from volcanic rock materials through which the water percolates, averages 42 mg/l, making the water undesirable for use in high-pressure boiler tanks. High sodium and chloride concentrations, 147 and 400 mg/l respectively, in a sample of ground water from the Columbia River Group suggest that saline water from underlying marine sedimentary rocks may have percolated into the basalt aquifers of the area. 98)

In the Eola-Amity Hills region, ground water from the Troutdale Formation, the alluvial deposits, and the Columbia River Group is soft to moderately hard and contains low to moderate concentrations of dissolved solids (85 to 273 mg/l). The marine sedimentary rocks found beneath the Columbia River Group contain highly mineralized water below a depth of 60 m (200 ft). 99)

In the Tualatin Valley, the quality of ground water is good. The average hardness of water from 500 wells tapping all the known fresh-water aquifers is about 115 mg/l. Deep wells in the valley fill have an average hardness of 124 mg/l. Saline ground water originating in rocks older than the Columbia River basalt is present in some areas. Upward migration of saline ground water from sedimentary rocks takes place in areas with unusual geologic structure. 6) Some modes of this movement of saline water are shown on Figure 32.

In the Portland-Vancouver area, ground water is generally of good quality. 5,96) Water from the Troutdale Formation and

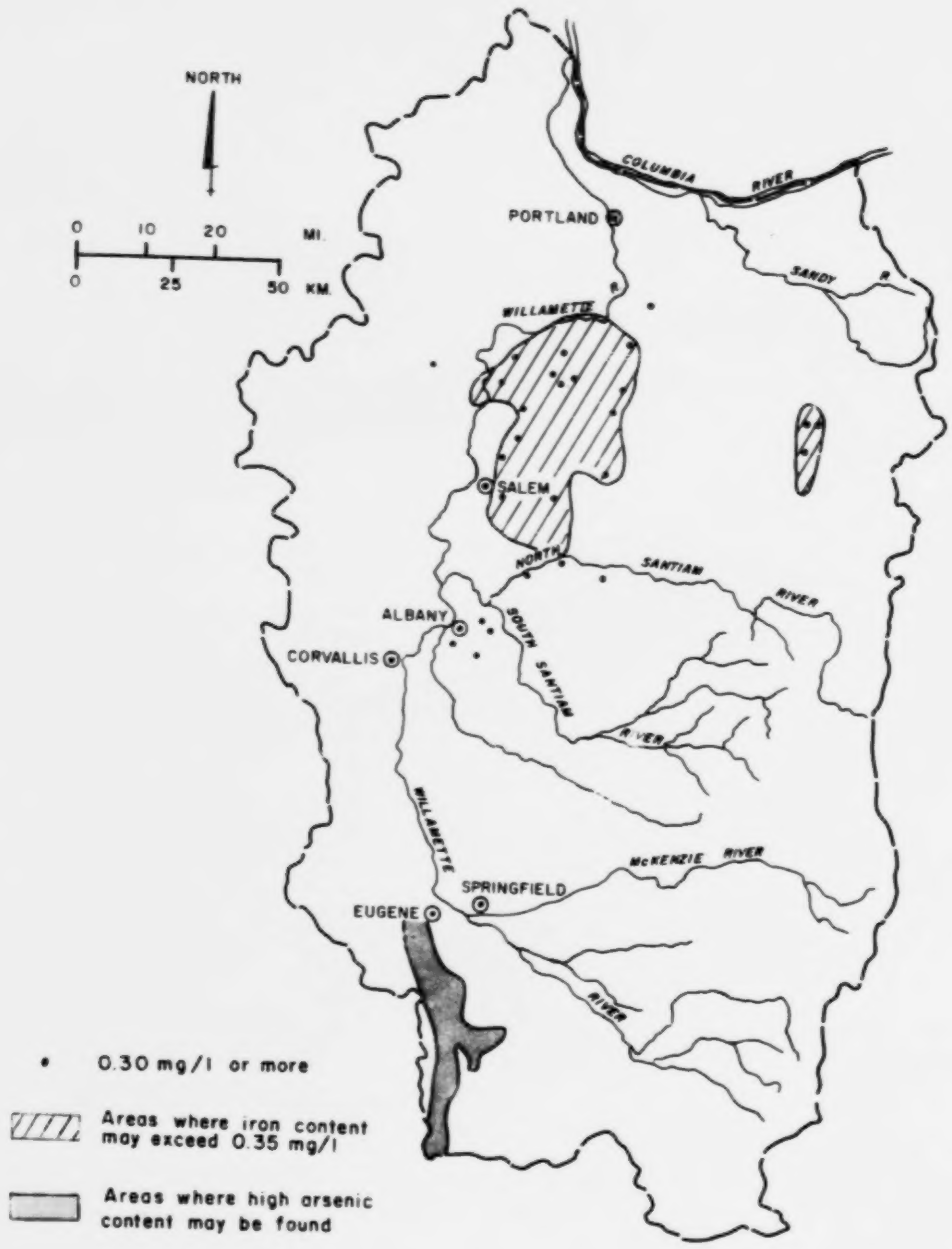
NORTH
0 10 20 MI.
0 25 50 KM.
COLUMBIA RIVER
PORTLAND
SANDY R.
WILLAMETTE R.
SALEM
NORTH SANTIAM RIVER
ALBANY
SOUTH SANTIAM RIVER
CORVALLIS
WILLAMETTE
McKENZIE RIVER
SPRINGFIELD
EUGENE
RIVER
• 0.30 mg/l or more
Areas where iron content may exceed 0.35 mg/l
Areas where high arsenic content may be found

Figure 31. Oregon - Iron and arsenic in ground water of the Willamette Basin. 109)

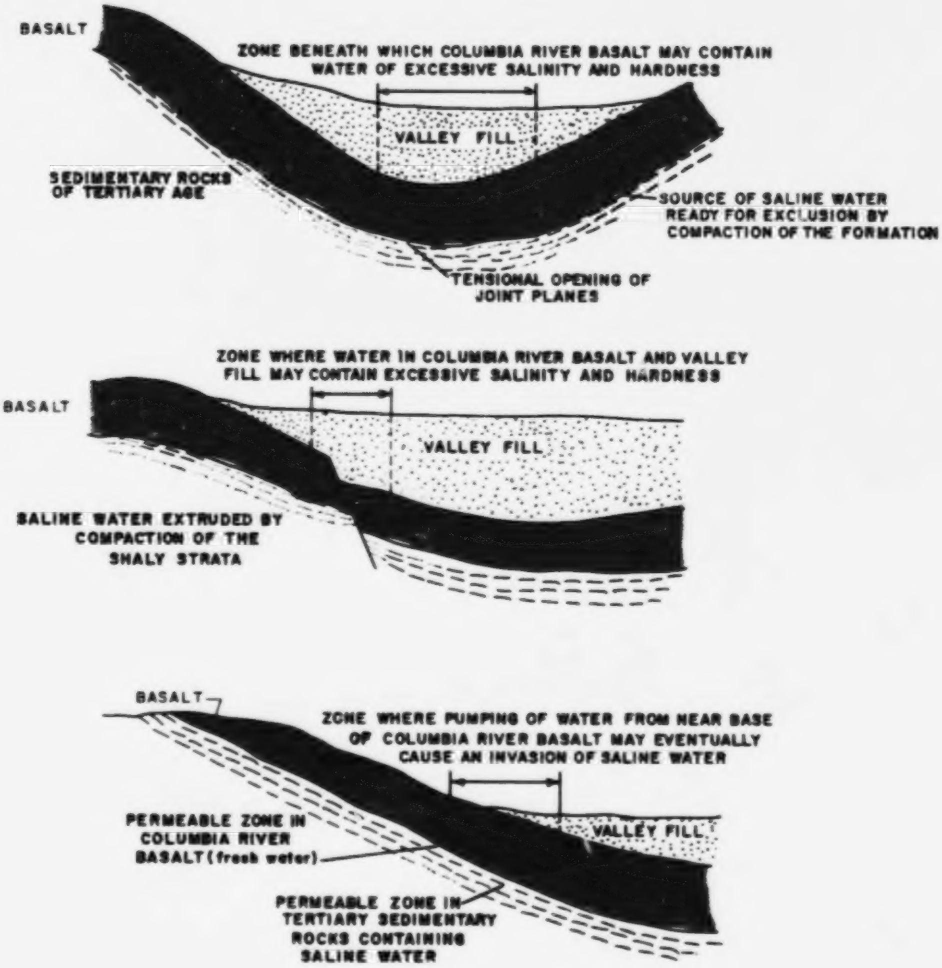
BASALT
ZONE BENEATH WHICH COLUMBIA RIVER BASALT MAY CONTAIN WATER OF EXCESSIVE SALINITY AND HARDNESS
VALLEY FILL
SEDIMENTARY ROCKS OF TERTIARY AGE
SOURCE OF SALINE WATER READY FOR EXCLUSION BY COMPACTION OF THE FORMATION
TENSIONAL OPENING OF JOINT PLANES
ZONE WHERE WATER IN COLUMBIA RIVER BASALT AND VALLEY FILL MAY CONTAIN EXCESSIVE SALINITY AND HARDNESS
BASALT
VALLEY FILL
SALINE WATER EXTRUDED BY COMPACTION OF THE SHALY STRATA
BASALT
ZONE WHERE PUMPING OF WATER FROM NEAR BASE OF COLUMBIA RIVER BASALT MAY EVENTUALLY CAUSE AN INVASION OF SALINE WATER
PERMEABLE ZONE IN COLUMBIA RIVER BASALT (fresh water)
VALLEY FILL
PERMEABLE ZONE IN TERTIARY SEDIMENTARY ROCKS CONTAINING SALINE WATER

Figure 32. Oregon - Upward migration of saline ground water in the Tualatin Valley. 6)

Boring Lava is generally softer and contains less dissolved solids than water from the Columbia River basalt and the unconsolidated deposits. The Columbia River basalt yields water with dissolved solids of 300 mg/l and a hardness of 120 mg/l. This water may contain excessive amounts of silica and iron. Wells drilled through the basalt into Tertiary marine sedimentary rock yield saline ground water.

The Troutdale Formation supplies moderately hard to hard ground water in the 60 to 150 mg/l range. Water from the Boring Lava is quite similar in chemical properties to water from the Troutdale Formation. Ground water in the alluvium, terrace sands and gravels, and other unconsolidated deposits is of good quality with dissolved solids of 110 to 500 mg/l and an average hardness of 110 mg/l. Local excessive concentrations of iron and silica occur in all aquifers. Upward migration of saline water as a result of pumping and subsequent lowering of artesian pressure in the basalt aquifer is taking place within the city of Portland. 97)

Medford and Ashland Areas -

Ground water in alluvial aquifers in the Medford and Ashland areas is usually hard. Nonmarine sedimentary rocks yield mostly calcium bicarbonate water. Near Medford, high fluoride, boron, and iron are encountered in some wells. 103,104) Highly concentrated sodium bicarbonate chloride water, locally known as Lithia water, is found in the nonmarine sedimentary rocks near Ashland. This ground water is bottled and converted into dry ice.

Coastal Belt -

Ground water in the coastal dune and beach sands is of good chemical quality. It is soft and contains only about 20 mg/l chloride. Some of the water contains excessive dissolved iron, and some may be sufficiently acid to require treatment for some uses. 110,111)

Eastern Oregon -

The ground water within the layered basalt of the Columbia River Group is of good quality. It is a generally uniform bicarbonate water having calcium and sodium in nearly equal concentrations as the principal cations. The water contains a relatively large amount of silica. Minor constituents, such as heavy metals and alkali metals, are present in small amounts, and the natural radioactivity of the ground water is low. Locally, the water contains some iron. Hydrogen sulfide gas is present in water from most wells, a common condition for water from the basalt of the Pacific Northwest. 15) Apparently the gas is released by decomposition of iron sulfides in the lava rock. Total dissolved solids in the ground water commonly range from 150 to 400 mg/l, and the hardness ranges from 50 to 250 mg/l. Some sodium-fluoride ground water is found in north-central Oregon (The Dalles-Umatilla syncline).

The quality of ground water from sedimentary deposits overlying the basalt varies. In the Umatilla River basin, the hardness ranges from 40 mg/l in the alluvium to 100 mg/l in glaciofluviatile deposits. 106) The average hardness of water from the alluvium in the Grande Ronde River basin is 90 mg/l. 108) Higher hardness (200 mg/l) and dissolved solids (400 mg/l) are reported from the alluvial deposits in the Deschutes River basin. 105)

Washington

The quality of ground water in Washington is generally good to excellent. In the humid part of the state, high precipitation and recharge to the aquifers tend to dilute the ground water in situ. Evaporation losses are low, and highly soluble or moderately soluble minerals are absent. East of the Cascades, most ground water is of good quality, but there are local problems of excessive dissolved solids. Large concentrations of iron, fluoride, and dissolved solids and high hardness in ground water are encountered in several local areas of the state. The following description of ground-water quality in the various regions is based largely on work done by Van Denburgh and Santos. 25) Additional water-quality data from more recent ground-water reports have been incorporated. Table 18 is a compilation of chemical analyses of selected constituents in natural ground waters.

Coast Range Peninsula -

The quality of the ground water in the glacial outwash deposits is excellent. Total dissolved solids are less than 250 mg/l, and hardness is less than 120 mg/l. Marginal to poor quality ground water is present in deep marine sedimentary rocks of Tertiary age in the Upper Chehalis River basin. In this area, total dissolved solids are greater than 500 mg/l and silica concentrations are usually greater than 30 mg/l. In the southeastern part of the Coast Range Peninsula region, ground water has iron concentrations above the 0.3 mg/l recommended limit for drinking water set by the U. S. Public Health Service (see Figure 33). Occurrences of saline ground water in the coastal zones probably reflect "relict sea water" resulting from incomplete flushing of salt water from rock

Table 18 . TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter). 26, 116 through 125)

	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Coast Range Peninsula									
Glaciofluvial and Alluvial Deposits	17	58 - 352	108	27	1.2 - 162	9.5	28	3 - 244	56
Puget Sound Province									
Glacial and Alluvial Deposits	165	58 - 2,360	116	122	0.2 - 990	5.4	119	8 - 504	54
Lewis River Province									
Glacial and Alluvial Deposits	10	67 - 310	137	11	0.8 - 16	3.8	11	14 - 162	60
Columbia Plateau									
Yakima River Valley									
Glacial and Alluvial Deposits	31	111 - 559	195	31	0.7 - 26	6.0	31	42 - 338	107
Basalt	22	114 - 416	214	22	1.2 - 106	6.0	22	39 - 250	84
Hanford									
Unconsolidated Deposits	19	128 - 431	202	19	1.5 - 26	6.8	19	80 - 274	115
Basalt	8	119 - 316	238	8	3.2 - 12	6.8	8	20 - 144	85

N - Number of samples
R - Range
M - Median

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter). 26, 116 through 125)

Location - Aquifer	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
	N	R	M	N	R	M	N	R	M
Columbia Plateau (Continued)									
Walla Walla Basin									
Gravel	5	139 - 555	-	8	3.5 - 25	8.2	7	70 - 219	176
Basalt	15	106 - 200	171	22	0.2 - 6.5	3.1	20	36 - 142	72
Southeastern Washington									
Sand and Gravel Deposits	26	149 - 1,740	321	28	1.6 - 90	9.9	28	92 - 1,220	180
Basalt	67	144 - 1,180	266	68	1.0 - 128	9.0	70	8 - 785	114
Northeastern Washington									
Glacial and Alluvial Deposits	28	50 - 364	170	29	0.0 - 14	1.8	29	31 - 274	153
Basalt	9	110 - 285	188	9	1.0 - 13	3.0	9	52 - 160	108

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter).[26, 116 through 125])

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Coast Range Peninsula									
Glaciofluvial and Alluvial Deposits	21	19 - 220	67	23	0.00 - 1.20	0.20	20	2.6 - 80	6.8
Puget Sound Province									
Glacial and Alluvial Deposits	93	18 - 411	62	102	0.00 - 6.4	0.12	149	1.4 - 314	6.9
Lewis River Province									
Glacial and Alluvial Deposits	11	16 - 103	52	11	0.00 - 4.8	0.02	11	1.6 - 9.3	5.1
Columbia Plateau									
Yakima River Valley									
Glacial and Alluvial Deposits	31	61 - 376	118	22	0.00 - 0.76	0.04	31	3.5 - 58	14
Basalt	21	70 - 202	134	18	0.00 - 0.79	0.06	22	7.2 - 54	24
Hanford									
Unconsolidated Deposits	19	66 - 196	119	19	0.00 - 5.2	0.03	19	3.5 - 34	17
Basalt	8	61 - 177	129	8	0.02 - 0.68	0.06	8	7.1 - 80	26

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter). 26, 116 through 125)

	Alkalinity ($CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Columbia Plateau (Continued)									
Walla Walla Basin									
Gravel	8	71 - 417	162	5	0.02 - 0.11	-	5	5.4 - 130	-
Basalt	20	59 - 122	88	14	0.0 - 0.77	0.04	11	6.2 - 32	9.4
Southeastern Washington									
Sand and Gravel Deposits	28	89 - 756	168	20	0.00 - 0.74	0.04	19	3.7 - 376	22
Basalt	55	74 - 241	148	79	0.00 - 2.4	0.07	73	8.4 - 86	32
Northeastern Washington									
Glacial and Alluvial Deposits	29	30 - 236	141	31	0.00 - 0.44	0.08	29	1.7 - 34	4.2
Basalt	9	51 - 135	118	8	0.02 - 0.20	0.04	8	5.3 - 26	14

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter), 26, 116 through 125)

	Sulfate (SO_4)			Nitrate (NO_3)			Silica (SiO_2)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Coast Range Peninsula									
Glaciofluvial and Alluvial Deposits	21	0.6 - 34	4.0	21	0.0 - 3.9	0.6	20	6.7 - 66	25
Puget Sound Province									
Glacial and Alluvial Deposits	95	0.0 - 103	3.9	129	0.0 - 20	0.3	122	3.6 - 82	30
Lewis River Province									
Glacial and Alluvial Deposits	11	0.6 - 41	7.4	11	0.3 - 44	7.2	11	14 - 64	44
Columbia Plateau									
Yakima River Valley									
Glacial and Alluvial Deposits	31	0.0 - 113	20	31	0.2 - 16	1.8	31	4.3 - 68	36
Basalt	22	0.1 - 46	3.0	22	0.0 - 10	0.1	22	18 - 65	51
Hanford									
Unconsolidated Deposits	19	15 - 113	27	19	0 - 16	1.8	19	4.3 - 70	31
Basalt	8	1.6 - 43	26	8	0.1 - 4.7	0.2	8	18 - 64	52

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter). 26, 116 through 125)

	Sulfate (SO_4)			Nitrate (NO_3)			Silica (SiO_2)		
Location - Aquifer	N	R	M	N	R	M	N	R	M
Columbia Plateau (Continued)									
Walla Walla Basin									
Gravel	7	3.5 - 38	16	7	0.2 - 8.6	5.8	7	34 - 58	43
Basalt	19	1.8 - 31	5.3	17	0.0 - 3.9	0.2	17	46 - 72	56
Southeastern Washington									
Sand and Gravel Deposits	27	9.1 - 811	29	27	0.0 - 51	4.1	26	11 - 71	42
Basalt	82	0.8 - 468	24	76	0.0 - 99	0.9	76	25 - 79	50
Northeastern Washington									
Glacial and Alluvial Deposits	29	3.7 - 109	15	29	0.0 - 32	3.1	29	9.0 - 29	15
Basalt	9	4.5 - 24	11	9	0.0 - 56	0.7	9	42 - 52	45

Table 18 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WASHINGTON. Concentrations in mg/l (milligrams per liter).[26, 116 through 125])

Location - Aquifer	pH N	pH R	pH M
Coast Range Peninsula			
Glaciofluvial and Alluvial Deposits	19	6.1 - 9.2	6.9
Puget Sound Province			
Glacial and Alluvial Deposits	141	6.0 - 9.2	7.5
Lewis River Province			
Glacial and Alluvial Deposits	10	6.2 - 8.0	7.0
Columbia Plateau			
Yakima River Valley			
Glacial and Alluvial Deposits	30	7.0 - 8.3	7.8
Basalt	19	7.1 - 9.2	7.8
Hanford			
Unconsolidated Deposits	19	7.4 - 8.3	7.8
Basalt	8	7.5 - 9.2	7.8
Columbia Plateau (Continued)			
Walla Walla Basin			
Gravel	5	7.3 - 8.0	-
Basalt	11	7.6 - 8.2	8.0
Southeastern Washington			
Sand and Gravel Deposits	17	7.4 - 8.1	7.9
Basalt	71	7.4 - 8.7	8.0
Northeastern Washington			
Glacial and Alluvial Deposits	24	6.7 - 9.4	7.8
Basalt	9	7.2 - 7.9	7.8

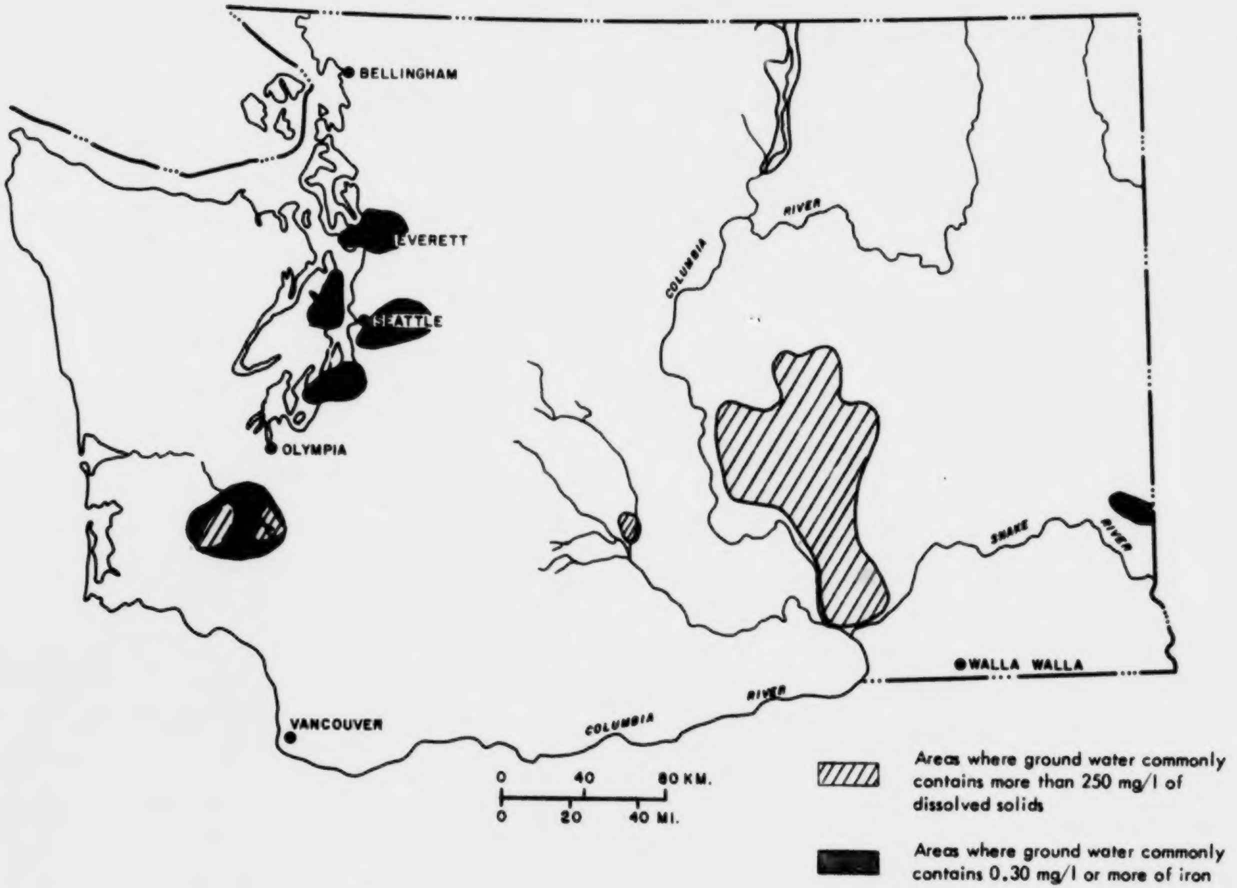
BELLINGHAM
EVERETT
SEATTLE
OLYMPIA
VANCOUVER
WALLA WALLA
COLUMBIA
RIVER
COLUMBIA
RIVER
SNAKE
RIVER
0
40
80 KM.
0
20
40 MI.
Areas where ground water commonly contains more than 250 mg/l of dissolved solids
Areas where ground water commonly contains 0.30 mg/l or more of iron

Figure 33. Washington - Dissolved solids and iron in ground water. 25)

materials following declines in sea level since Pleistocene times. The saline water could also represent true connate water that has been in the aquifer since its formation. 122)

Puget Sound Province -

The quality of most ground water in the Puget Sound province is good to excellent. Most of the ground water contains less than 150 mg/l dissolved solids and is soft. Isolated inland occurrences of water with large amounts of dissolved solids are due to pumpage from aquifers in marine sedimentary deposits or incompletely flushed connate water. In the coastal areas, saline ground water is present at depth, and upward migration of saline water is possible as a result of pumping from the shallow fresh-water aquifer.

Several areas in and adjacent to Puget Sound yield ground water with concentrations of iron above the 0.3 mg/l recommended limit. Silica is present in ground water in the range of 7 to 60 mg/l, but most values fall within the 25 to 40 mg/l range. Ground water with high silica content usually occurs in older and deeper aquifers. Iron concentrations are high in ground water in the Everest area of Snohomish County. No obvious relationship exists between aquifer depth, age, and high iron concentrations, although proximity to Tertiary rocks seems to be a factor in some places. 123) Peat sediments in deposits of Pleistocene and Recent age may also indirectly contribute to iron-rich ground water. 116) In the northern half of the province, ground water is moderately hard (61 to 120 mg/l).

Lewis River Province -

The quality of most ground water in the Lewis River province is excellent. Dissolved solids are generally less than 150 mg/l, and the hardness is usually less than 100 mg/l. Silica in concentrations of more than 30 mg/l is present in most well waters. Local high iron concentrations occur.

Columbia Plateau -

Ground water of the Columbia Plateau varies in chemical character. In irrigated areas, the sedimentary deposits of Pleistocene age that overlie the basalt contain ground water of fairly poor quality as a result of irrigation returns. The hardness of this ground water commonly exceeds 180 mg/l, and the total dissolved solids are often above 500 mg/l. Elsewhere, the dissolved solids are characteristically less than 250 mg/l.

The chemical nature of ground water native to the Columbia River basalt is rather uniform. It has a moderate dissolved solids content of about 275 mg/l, with calcium, sodium, bicarbonate, and silica as the principal constituents. Much of the ground water has a slight hydrogen sulfide odor. 15) The silica ranges between 40 and 80 mg/l. Iron concentrations in this aquifer are generally below 0.3 mg/l, but locally higher concentrations do occur.

Many wells in the Pullman-Moscow area experience excessive iron in ground water. 124) Deeper basalt aquifers sometimes yield more mineralized water, but studies of the relation of depth to quality show only some general differences. Water at greater depths has less calcium, magnesium, and bicarbonate but contains more sodium and potassium. 15) Sulfate in the basalt ranges from 10 to 50 mg/l and averages 20 mg/l.

Higher sulfate concentrations (50 to 250 mg/l) occur in the upper zone of the basalt aquifer within the Columbia Basin Irrigation Project area in Adams, Franklin, and Grant Counties. Ground water in the Walla Walla River basin is generally of excellent quality. It is low in mineral content, and soft to moderately hard. 112)

At the Hanford Reservation, the ground-water quality in the unconsolidated aquifer has changed as a result of radioactive waste disposal. The average concentrations of some constituents in the ground water prior to significant disposal of waste indicates a good quality water low in sulfates (21.5 mg/l), nitrates (2.2 mg/l), sodium (19.4 mg/l), and calcium (28.6 mg/l). 121)

Northeast -

Ground water in the alluvial, glacial, and terrace deposits along the Okanogan and Wenatchee Rivers is hard and contains more than 250 mg/l dissolved solids. Mineralization of ground water increases with depth. In the eastern part of the province, particularly in the Spokane River valley, ground water in similar deposits usually contains less than 200 mg/l dissolved solids and has a hardness less than 150 mg/l. The silica content of ground water is less than 30 mg/l. Long-term chemical quality records in the Spokane and Curlew areas show no overall change in chemical character of the ground water, although shallow ground water exhibits slight year-to-year fluctuations as a result of irrigation. Local problems of excessive iron occur in the Spokane area. 125)

Wyoming

The quality of the ground water in Wyoming is variable. The alluvial aquifers yield moderately hard to very hard water (over 200 mg/l). Sandstone aquifers yield soft to very hard water depending on depth, age, and closeness to recharge areas. Sandstones of Cretaceous and Jurassic age generally yield softer water than younger (Tertiary) or older (Paleozoic) rocks. The median total dissolved solids of ground water in unconsolidated aquifers and sandstones shallower than 300 m (1,000 ft) is about 500 mg/l, equivalent to the U. S. Public Health Service's recommended upper limit for drinking water. In deeper aquifers, the median total dissolved solids concentration is over 2,000 mg/l. 4) Total dissolved solids concentrations of ground water in various aquifers are given in Table 7 in Section IV of this report. A compilation of chemical analyses of selected constituents in natural ground waters is shown in Table 19.

More than 60 percent of Wyoming is underlain by saline ground water. Figure 34 shows the depth to ground water containing more than 1,000 mg/l dissolved solids. A short description of ground-water quality in the various basins in given below.

Green River Basin -

The quality of ground water in the Green River basin varies from very poor to excellent. Water in the sand and gravel deposits and in the more permeable sandstone of the Wasatch Formation near the surface in the northern two-thirds of Sublette County generally contains less than 500 mg/l total dissolved solids. In southern Sublette County and further south, water ranging from 500 to 3,500 mg/l in dissolved solids is generally available from at least one aquifer; other aquifers may contain more highly mineralized water.

A deltaic sandstone in the New Fork Tongue of the Wasatch Formation extending some 1,300 to 3,100 sq km (500 to 1,200 sq mi), contains several artesian zones. This aquifer, overlain by the Green River Formation which contains exploitable oil shales, is available as a source of water for the oil shale industry. The water, however, is not potable because of excessive concentrations of fluoride (6.5 to 14.0 mg/l) and total dissolved solids (690 to 2,200 mg/l). 20)

Near Farson and Edin in the northern part of the Green River basin, black artesian ground water has been encountered in permeable oil shales of the Green River Formation. The black color is caused by organic acids dissolved in a sodium bicarbonate solution. The origin of the ground water is not

Table 19 . TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING. Concentrations in mg/l (milligrams per liter).[22, 130 through 133]

Location and Rock Type	Dissolved Solids (residue on evaporation at 180°C)			Chloride (Cl)			Hardness ($CaCO_3$)		
	N	R	M	N	R	M	N	R	M
Northeast									
Alluvium	16	82 - 3,340	1,240	16	0.0 - 194	6.8	16	38 - 1,240	326
Wasatch Formation	17	281 - 6,620	890	17	2.0 - 45	10	17	12 - 3,310	461
Fort Union Formation	19	484 - 3,250	1,310	19	3.7 - 63	14	19	16 - 2,310	55
Lance Formation	12	450 - 3,060	1,310	12	4.0 - 110	10	12	12 - 1,710	92
Parkman Sandstone	8	550 - 22,060	4,880	8	1.6 - 11,700	1,720	2	212 - 407	-
Frontier Formation	7	390 - 24,950	8,040	7	1.7 - 13,800	4,650	2	174 - 731	-
Inyan Kara Group	28	218 - 18,706	1,370	28	2.0 - 10,000	49	8	62 - 1,340	196
Minnelusa Formation	25	551 - 199,782	4,350	25	1.0 - 120,000	310	6	431 - 2,840	-
Platte River Basin									
Alluvium	13	260 - 692	390	13	3.0 - 19	9.2	13	147 - 452	187
Terrace Deposits	8	234 - 786	495	8	4.0 - 19	13	8	123 - 484	288
Arikaree Formation	18	176 - 831	287	18	2.0 - 119	12	19	69 - 556	170
Brule Formation	8	251 - 616	399	7	4 - 52	9	7	110 - 311	202
Bighorn River Basin									
Alluvium	34	256 - 4,600	1,040	28	0.1 - 95	17	34	138 - 1,280	412
Terrace Deposits	22	265 - 3,310	956	23	0.0 - 44	9.5	23	68 - 1,420	384
Wind River Formation	39	203 - 5,000	872	39	0 - 416	20	36	3 - 1,810	88
Frontier Formation	8	1,170 - 13,071	2,138	10	4 - 7,500	92	4	8 - 126	-
Chugwater Group	4	3,040 - 41,505	-	7	26 - 15,850	6,200	1	157	-
Tensleep Sandstone	2	801 - 2,567	-	8	8 - 920	42	2	556 - 573	-

N - Number of samples
R - Range
M - Median

Table 19 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING.[22, 130 through 133] Concentrations in mg/l (milligrams per liter).

Location and Rock Type	Dissolved Solids (residue on evaporation at 180°C) N	R	M	Chloride (Cl) N	R	M	Hardness ($CaCO_3$) N	R	M
Southwest									
Alluvium	16	209 - 3,210	484	18	3.5 - 272	18	17	3 - 1,220	228
Gravel Deposits	8	65 - 2,460	310	8	0.9 - 726	6.8	6	52 - 983	-
Laney Shale	14	562 - 3,450	1,380	14	4.9 - 394	22	14	2 - 2,020	214
Tipton Shale	7	555 - 3,700	781	7	16 - 1,700	26	2	6 - 18	-
Wasatch Formation	46	215 - 3,590	869	47	0.7 - 3,070	18	46	0 - 1,610	36

Table 19 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING. Concentrations in mg/l (milligrams per liter).[22, 130 through 133)

	Alkalinity (as $CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location and Rock Type	N	R	M	N	R	M	N	R	M
Northeast									
Alluvium	16	48 - 601	322	15	0.00 - 11	1.3	16	4.7 - 970	178
Wasatch Formation	16	138 - 753	392	17	0.03 - 25	0.26	17	3.4 - 800	202
Fort Union Formation	15	110 - 1,943	610	19	0.08 - 9.0	0.26	19	39 - 943	400
Lance Formation	11	228 - 1,123	451	12	0.00 - 8.6	0.10	12	150 - 922	360
Parkman Sandstone	8	271 - 2,075	895	2	0.22 - 1.3	-	2	29 - 366	-
Frontier Formation	7	144 - 3,165	1,300	2	0.02 - 2.9	-	2	74 - 299	-
Inyan Kara Group	24	152 - 1,730	466	7	0.01 - 5.5	0.74	7	56 - 486	70
Minnelusa Formation	20	130 - 1,091	240	4	0.05 - 0.55	-	3	4.1 - 29	-
Platte River Basin									
Alluvium	9	134 - 285	217	13	0.02 - 1.2	0.03	11	13 - 77	34
Terrace Deposits	4	134 - 254	-	8	0.01 - 0.11	0.02	6	11 - 75	-
Arikaree Formation	14	108 - 284	163	18	0.00 - 0.27	0.04	18	7.5 - 126	29
Brule Formation	4	154 - 456	-	8	0 - 1.1	0.02	5	32 - 122	-
Bighorn River Basin									
Alluvium	25	154 - 503	307	23	0.0 - 1.3	0.20	31	7 - 1,100	93
Terrace Deposits	19	129 - 423	317	20	0.01 - 0.34	0.10	16	24 - 460	136
Wind River Formation	38	18 - 385	125	25	0.02 - 3	0.28	38	15 - 1,500	260
Frontier Formation	10	136 - 6,703	848	2	0.20 - 0.21	-	4	435 - 772	-
Chugwater Group	6	111 - 2,481	-	1	0.50	-	-	-	-
Tensleep Sandstone	8	132 - 1,279	365	-	-	-	2	49	-

Table 19 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING. Concentrations in mg/l (milligrams per liter). 22, 130 through 133)

	Alkalinity (as $CaCO_3$)			Iron (Fe)			Sodium (Na)		
Location and Rock Type	N	R	M	N	R	M	N	R	M
Southwest									
Alluvium	18	103 - 533	242	8	0.0 - 7.0	0.78	7	16 - 265	67
Gravel Deposits	6	80 - 568	-	7	0.02 - 0.40	0.03	7	2.8 - 500	21
Laney Shale	14	110 - 1,607	266	6	0.0 - 0.77	-	8	99 - 1,290	240
Tipton Shale	7	221 - 1,427	298	2	0.05 - 0.14	-	7	217 - 1,470	298
Wasatch Formation	47	0 - 1,410	295	34	0.00 - 61	0.11	37	17 - 1,190	258

Table 19 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING. Concentrations in mg/l (milligrams per liter). 22, 130 through 133)

	Sulfate (SO_4)			Nitrate (NO_3)			pH		
Location and Rock Type	N	R	M	N	R	M	N	R	M
Northeast									
Alluvium	16	3.3 - 1,950	474	14	0.0 - 3.5	0.4	16	6.7 - 8.2	7.6
Wasatch Formation	17	1.3 - 4,080	284	13	0.0 - 19	3.8	17	6.8 - 8.3	7.5
Fort Union Formation	19	0.3 - 1,870	55	13	0.0 - 11	1.0	19	7.0 - 8.8	7.9
Lance Formation	12	0.3 - 1,780	508	12	0.0 - 13	0.4	12	7.0 - 8.5	7.8
Parkman Sandstone	8	39 - 1,312	266	2	0.0 - 4.3	-	2	7.8 - 8.1	-
Frontier Formation	7	0 - 1,250	70	2	0.4 - 3.2	-	2	7.1 - 8.1	-
Inyan Kara Group	25	15 - 1,413	292	7	0.0 - 13	0.1	7	7.3 - 8.0	7.6
Minnelusa Formation	25	203 - 5,452	1,890	3	0.1 - 2.2	-	4	7.0 - 7.5	-
Platte River Basin									
Alluvium	13	14 - 296	61	13	0.1 - 19	5.5	12	7.3 - 8.0	7.6
Terrace Deposits	8	8.6 - 280	158	8	0.16 - 28	3.4	7	7.3 - 8.1	7.7
Arikaree Formation	19	0.1 - 328	27	17	0.0 - 26	6.4	19	6.8 - 8.4	7.7
Brule Formation	7	15 - 197	33	7	0.6 - 29	16	6	7.3 - 8.4	-
Bighorn River Basin									
Alluvium	28	47 - 2,450	671	13	0.0 - 10	2.2	34	7.2 - 8.2	7.7
Terrace Deposits	23	20 - 1,880	390	23	0.6 - 40	13	23	7.4 - 8.4	7.8
Wind River Formation	39	23 - 3,250	440	38	0.0 - 44	0.3	39	6.8 - 9.7	7.9
Frontier Formation	10	0 - 2,700	68	3	0.0 - 10	-	4	7.9 - 9.1	-
Chugwater Group	7	1,830 - 12,139	8,890	1	2.7	-	1	8.0	-
Tensleep Sandstone	8	67 - 2,296	990	1	0.1	-	1	7.3	-

Table 19 (Continued). TABULATION OF SELECTED CHEMICAL ANALYSES OF GROUND WATER IN WYOMING. Concentrations in mg/l (milligrams per liter). 22, 130 through 133)

Location and Rock Type	Sulfate (SO_4)			Nitrate (NO_3)			pH		
	N	R	M	N	R	M	N	R	M
Southwest									
Alluvium	17	7.4 - 1,760	170	16	0.0 - 1.9	0.6	18	6.8 - 8.8	7.4
Gravel Deposits	8	7.2 - 695	28	6	0.1 - 14	-	8	7.3 - 8.1	7.6
Laney Shale	14	65 - 2,140	456	13	0.0 - 126	1.0	14	7.2 - 9.0	8.0
Tipton Shale	7	2.1 - 226	157	2	0.0 - 0.2	-	7	8.3 - 9.3	9.1
Wasatch Formation	47	0.2 - 2,020	195	44	0.0 - 10	0.1	48	4.4 - 9.7	8.2

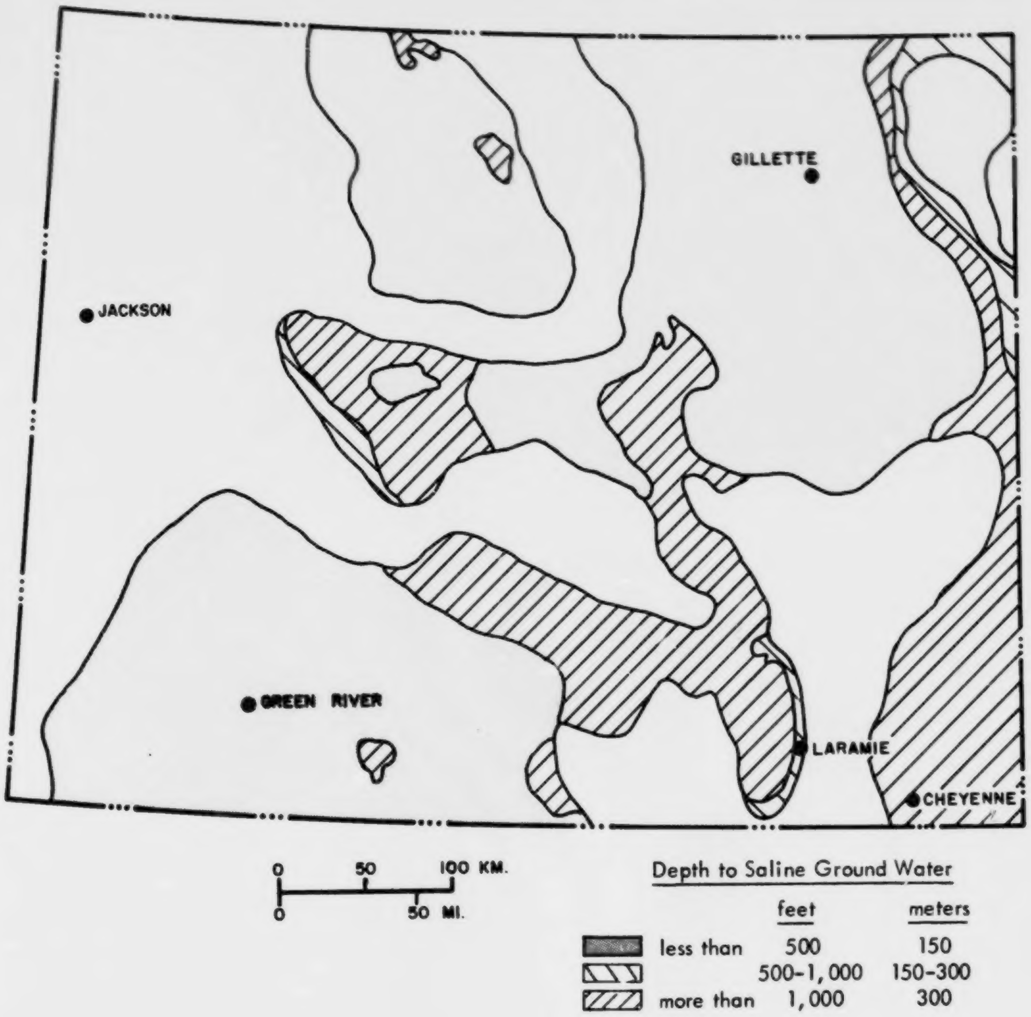
GILLETTE
JACKSON
GREEN RIVER
LARAMIE
CHEYENNE
0 50 100 KM.
0 50 MI.
Depth to Saline Ground Water
feet meters
▨ less than 500 150
▧ 500-1,000 150-300
▨ more than 1,000 300

Figure 34. Wyoming - Depth to ground water containing more than 1,000 mg/l dissolved solids.[2)]

clear, but the black water may be original lake water incorporated in the sediments during recession of an ancient lake in the geologic past. 130)

In general, ground water in the Green River basin becomes more mineralized with increasing depth, and below 600 m (2,000 ft), total dissolved solids over 1,000 mg/l may be expected. Some exceptions occur in the Great Divide and Washakie Basins, where zones of good quality water in the Wasatch, Fort Union, and Lance Formations are overlain by zones of poorer quality water.

The sand and gravel deposits in the north and southwest, in the Wasatch Formation in the north, and other Tertiary rocks in the north and northeast, would yield water suitable for irrigation, if adequate quantities could be obtained. Water in the Green River and Wasatch Formations in the southern two-thirds of the basin is not suitable for irrigation because of a high sodium content. Some of the ground water from the Wasatch, Green River, and Bridger Formations is high in fluoride. 129) In the Great Divide and Washakie Basins, ground water having a concentration of less than 1,000 mg/l of total dissolved solids can be found in about one-third of the area; elsewhere the water is poorer in quality. Locally excessive concentrations of iron, sulfate, and fluoride occur in the ground water. 128)

Snake River Basin -

Ground water is generally hard to very hard within Grand Teton National Park. Some ground water is soft and has total dissolved solids of less than 100 mg/l. Water from the alluvial deposits in the Star Valley contains less than 300 mg/l of total dissolved solids. 131)

Bighorn River Basin -

Ground water in the alluvial deposits varies in concentration from 250 to 4,000 mg/l of total dissolved solids but generally contains less than 1,000 mg/l of total dissolved solids. The quality of ground water in the floodplain and terrace deposits is affected by irrigation returns. 132,133) Waterlogging has occurred in many irrigated areas. Ground water from the alluvial deposits below the Riverton Irrigation Project area in the Wind River basin is highly mineralized and unsuitable for domestic and irrigation use. 134,135) In the Greybull River-Dry Creek area, a direct correlation exists between sulfate concentrations and mineralization of ground water. Concentrations of sulfate exceed 250 mg/l in water from two-thirds of the wells and springs, and are accompanied by concentrations of total dissolved solids of over 500 mg/l. 136)

In Sheridan County, water from the alluvium has a medium to very high salinity hazard rating with a total dissolved solids concentration ranging from 272 to 2,060 mg/l. Iron and sulfate concentrations are also above U. S. Public Health Service recommended limits for drinking water. 137) Where the quality of surface-water recharge is good, the alluvium yields better quality water. Water from the Fort Union and Wasatch Formations is hard and of poor quality. Methane gas is produced together with water in many wells penetrating coal beds in the two formations.

Northeastern Wyoming -

The quality of ground water varies greatly from area to area according to aquifer, depth, nearness to recharge area, irrigation practices, and presence of evaporites in the subsurface. In the alluvial aquifers, the water is generally very hard, mineralized, and contains high concentrations of iron. Ground water in the alluvium is often of better quality in the upstream areas where better quality recharge water is available. In the river valleys, the ground-water quality reflects the chemical characteristics of springs and seeps from Tertiary and older aquifers that recharge the alluvium. The dissolved solids of ground water from alluvium vary from 1,000 to 3,000 mg/l. 138)

The ground water from most consolidated formations is hard and contains concentrations of iron, sulfate, and dissolved solids in excess of U. S. Public Health Service recommended limits for drinking water. Most ground water is suitable for stock watering, but is of limited use for irrigation.

The Arikaree Formation is an important aquifer in Niobrara County and furnishes moderate to large quantities of water to wells. The hardness of the ground water from the Arikaree Formation ranges from 165 to 340 mg/l, and dissolved solids range from 230 to 535 mg/l. 139)

In the Gillette area, a rapidly developing industrial and coal mining center, small quantities of water are available from the Wasatch and Fort Union Formations. Water in the Fox Hills sandstone of late Cretaceous age contains excessive concentrations of dissolved solids. 140)

Platte River Basin -

The ground-water quality of the alluvial and terrace deposits is generally fair to good. The water is hard and the aquifer is susceptible to degradation from irrigation returns and from pollution on the land surface. Problems of waterlogging occur in the Wheatland Flats area. 141) In some places, the ground water in floodplain deposits contains excessive concentrations of iron and nitrate. 142,143,144)

Water from aquifers of Tertiary age varies in quality. The Ogallala Formation yields hard water satisfactory for most domestic and stock uses. Water from the North Park, Browns Park, Arikaree, and Battle Spring Formations is of fair to good quality. Some local problems of excessive fluoride concentrations are reported in ground water from the Lance Formation. 142)

Ground water from the White River, Wasatch, and Fort Union Formations is locally unsuitable for drinking. In the pre-Tertiary sediments, ground water is of variable quality with a range of total dissolved solids from 200 to 100,000 mg/l. Ground-water quality is best near the recharge areas, but deteriorates toward the interior of the sedimentary basins.

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SECTION VI

SOURCES OF GROUND-WATER CONTAMINATION

INTRODUCTION

In previous sections of this report, the general geologic and hydrologic character of the project area was described. In addition, a description of the natural ground-water quality was presented including many of the naturally occurring ground-water problems. In this section, a discussion of ground-water pollution or ground-water contamination problems is presented. The terms "pollution" and "contamination" are synonymous and mean the degradation of natural water quality as a result of man's activities to the extent that its usefulness is impaired. There is no implication of any specific limits (such as those in the U. S. Public Health Service drinking water standards), as the degree of permissible pollution depends upon the intended end use, or uses, of the water.

Concern about potential pollution of ground water in the nation was expressed by investigators from the U. S. Geological Survey as much as 70 years ago. 1) Since that time a number of studies have been conducted pertaining to ground-water contamination. 2,3,4) However, until recent years, government agencies at all levels were primarily concerned with surface-water contamination, and only slight attention was given to ground-water contamination. The more apparent loss of rivers and lakes as water supply sources and as recreation areas always initiated quicker public action than the more obscure degradation of a ground-water reservoir. Only when a regional ground-water supply is threatened by pollution from septic tanks or discharge of toxic wastes, or when a surface discharge point is contaminated, are controls recommended and implemented.

As man's activities consume greater amounts of land and as population and industry increase, greater volumes of ground water are subject to potential contamination. Control and prevention of ground-water contamination are required to safeguard this vital water source for future generations.

Movement of Waste Fluids

To understand the health and other hazards associated with ground-water contamination, some familiarity with the basic principles of movement of contaminants in a ground-water body is necessary. Ground water can simply be described as water contained in the saturated pore spaces and fractures of hard rocks and sediments beneath the land surface. It does not exist in a static condition but is constantly in motion. The rate of ground-water movement is highly variable both vertically and horizontally, and may vary from meters per day to centimeters per day or less. For example, in fractured crystalline rock the movement might be on the order of tens of meters per day, whereas in unconsolidated material it might be a few centimeters per day.

The configuration and slope of the water table are important considerations in estimating the directions and rates of travel of wastes in the subsurface environment. Contaminants dumped in an area where the water table is practically flat and where little movement of ground water is occurring will tend to stay in place. On the other hand, it should be kept in mind that low gradients can be associated with high aquifer transmissivities in a given area, and high gradients with low transmissivities. Where transmissivities are great, the pollutant can move rapidly in spite of a relatively flat water table.

The thickness and composition of the unsaturated zone overlying the saturated zone are also important factors. Especially in cases of biological contamination, a thick unsaturated zone of fine-grained soil can adsorb and filter some or all of the pollutants before they can be introduced into the ground-water body itself.

Once at the top of the water table, fluid wastes generally will enter the ground-water system with only minor mixing with native ground water or will float (hydrocarbons for instance) on top of the saturated zone. Figure 35 shows a typical case involving the percolation of contaminants through the unsaturated zone into a water-table aquifer. The contaminant will then move with the ground water toward its ultimate discharge point, which commonly is a spring or a river. Frequently, however, ground-water flow patterns are modified because of pumping from nearby wells. In such cases, the hydraulic gradient or slope of the water table is toward such a well, and the contaminants converge upon the center of pumping and emerge in the well discharge. In most cases, this is exactly how ground-water pollution is discovered.

Under natural conditions and in the absence of pumping, water-table aquifers in the more humid portions of the study region discharge ground water continuously into a nearby surface-water body such as a lake or river. Thus, the ground water is entering the lake or stream and the aquifer

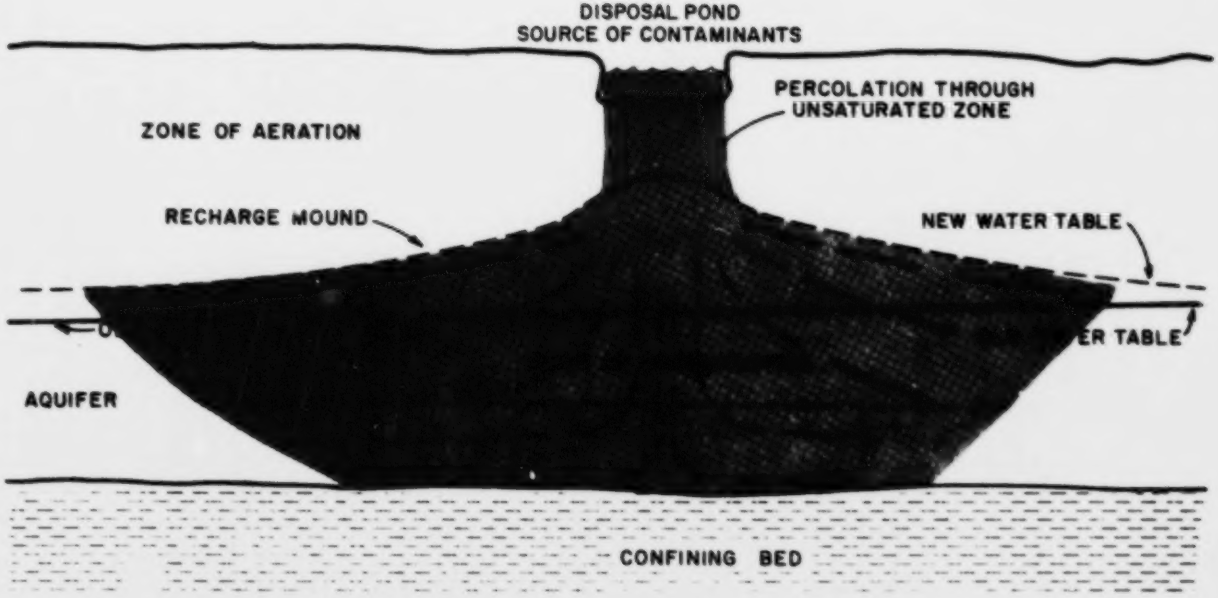

DISPOSAL POND
SOURCE OF CONTAMINANTS
PERCOLATION THROUGH
UNSATURATED ZONE
ZONE OF AERATION
RECHARGE MOUND
NEW WATER TABLE
ER TABLE
AQUIFER
CONFINING BED

Figure 35. Movement of contaminated ground water beneath leaky disposal pond. 5)

itself cannot be contaminated by wastes carried by the stream. When a well is put in operation in such an aquifer near a stream, however, ground-water levels are lowered and the hydraulic gradient between the well and river may be reversed, causing surface water to flow toward the well. If the stream is polluted, contaminated river water may thereby be induced to flow to the well. This situation is shown on Figure 36.

According to the laws governing fluid movement in saturated material, the direction of ground-water flow will always be toward points where the total hydraulic head is lowest. In many parts of the Northwest, saline ground water in deep aquifers is under high artesian heads, and it can be induced to move upward into fresh-water aquifers where heads are lower. An example would be the situation in which two zones are interconnected through abandoned or improperly sealed wells, as shown on Figure 37.

Sources of Ground-Water Contamination

A wide variety of harmful substances is regularly introduced into subsurface formations and aquifers of the Northwest. These substances enter ground-water supplies by direct injection through wells, by percolation of liquids spilled at the land surface or leached from soluble solids at the surface, by leaking or broken sewers and pipelines, by downward seepage from waste lagoons, and by infiltration of polluted surface water into the ground. To the list should be added contamination of ground water caused by infiltration of irrigation return water, seawater encroachment, and upward coning of salty ground water into fresh-water aquifers.

One recognized threat to ground-water quality comes from improperly designed landfills. Rainfall entering the landfill through its exposed surface comes in contact with the refuse and dissolves organic and inorganic compounds to form a concentrated solution called leachate. The leachate then percolates downward to contaminate an underlying aquifer.

Septic tanks, which are in use in all unsewered communities and rural areas of the Northwest, are other sources that have caused measurable pollution.

Disposal of industrial wastes in pits or lagoons is another widespread practice. When improperly constructed, such lagoons can leak untreated wastes containing such constituents as hexavalent chromium, cadmium, cyanide, and caustic soda into the subsurface.

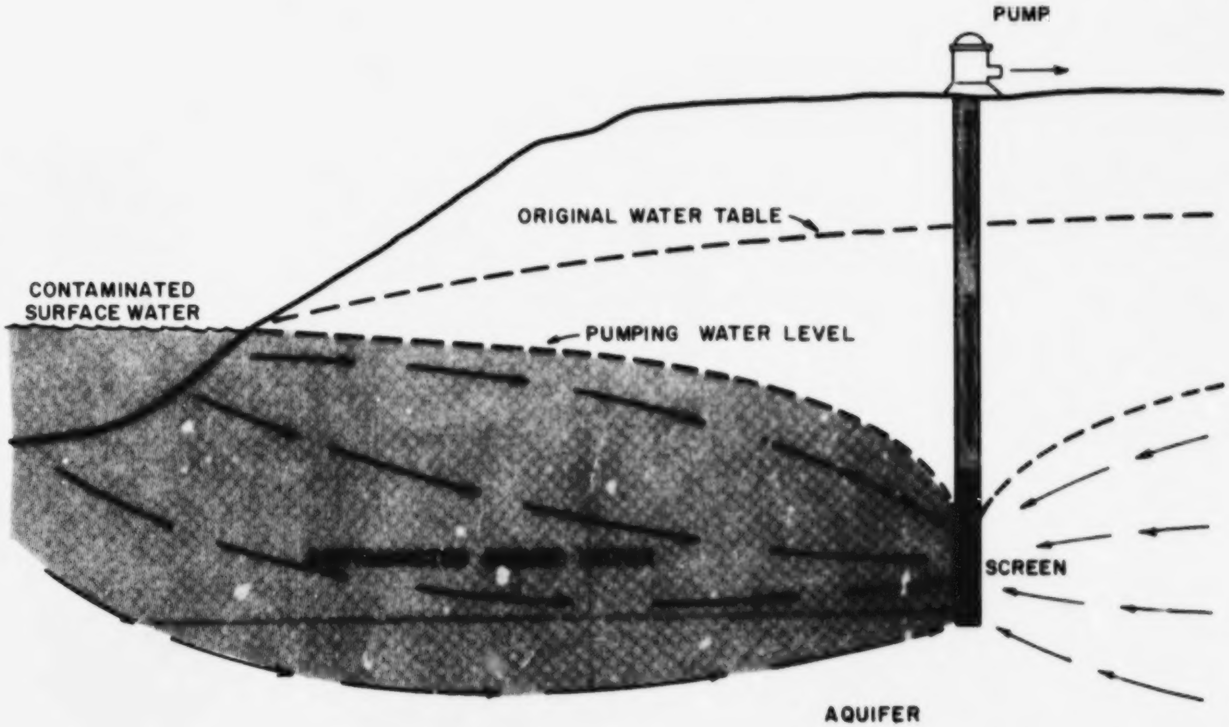

PUMP
ORIGINAL WATER TABLE
CONTAMINATED SURFACE WATER
PUMPING WATER LEVEL
SCREEN
AQUIFER

Figure 36. Movement of contaminated surface water to a pumping water well. 5)

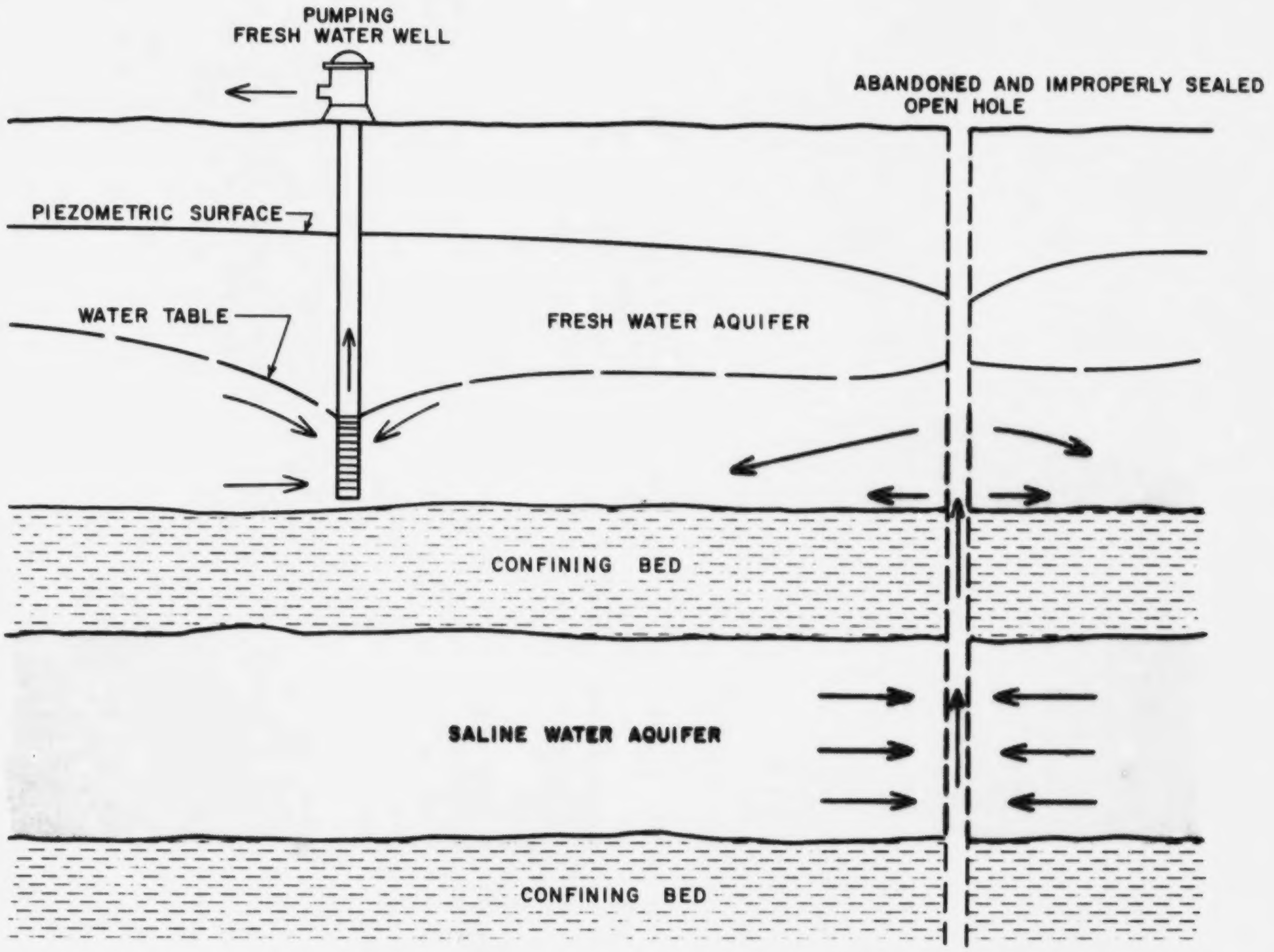

PUMPING
FRESH WATER WELL
ABANDONED AND IMPROPERLY SEALED
OPEN HOLE
PIEZOMETRIC SURFACE
WATER TABLE
FRESH WATER AQUIFER
CONFINING BED
SALINE WATER AQUIFER
CONFINING BED

Figure 37. Movement of deep saline ground water into a fresh-water aquifer by means of an improperly sealed open hole.5)

Percolation of liquids spilled at the land surface can be a serious threat if the surficial materials are permeable and allow downward percolation. Storage of chemicals, chemical wastes, petroleum products or radioactive waste fluids in steel or concrete tanks also presents a potential hazard because corrosion of the metal or cracking of the concrete may ultimately permit seepage of contaminants into an aquifer. Leaching of soluble solids stored on the land surface is still another practice that can be responsible for contamination of ground water. Such incidents occur, for example, where rain water dissolves soluble materials and enters the ground from mine waste piles and stockpiles of highway deicing salt.

Deep-well disposal (disposal of liquid wastes through wells into porous and permeable rock formations) by industry is rare in the project area. However, a widespread agricultural practice in Idaho is the disposal of irrigation surface runoff water into shallow disposal wells. Such operations may threaten ground-water quality. Oil and gas wells can also be a threat, for example, when injected oil field brines pass into fresh-water aquifers as a result of corroded or ruptured well casing.

Another kind of ground-water contamination takes place when salt water encroaches and enters a fresh-water aquifer. Salt-water intrusion occurs mainly in coastal areas where pumping has decreased the natural seaward flow of fresh ground water. However, it can also take place in inland localities when pumping induces deep salty waters to cone upward into fresh-water beds.

A summary of the principal sources of ground-water contamination in the Northwest is given in Table 20, in order of their importance. The size of the areas affected and the future trend in rate of new occurrences have also been estimated. It should be noted that the relative importance of a particular source of ground-water contamination varies from state to state. For instance, radioactive waste disposal takes place primarily in Idaho and Washington, while oil and gas activities are limited to Colorado, Montana and Wyoming.

Sewage disposal and irrigation return flow are the two principal sources of ground-water contamination in the Northwest. Increased salinity in ground water caused by irrigation practices is often of regional nature and affects a larger volume of ground water than sewage disposal. However, discharges from septic tanks and sewage treatment plants have a greater impact on ground-water quality in more populated areas and are therefore ranked above irrigation return flow

Table 20. PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION AND THEIR RELATIVE IMPACT IN THE NORTHWEST.

Sources	Relative importance to region a)	Typical size of area affected b)	Estimated future trend in rate of new occurrences c)
Septic systems	I	II	I
Sewage treatment plant discharge	I	II	I
Irrigation return flow	I	I	II
Dryland farming	I	II	I
Abandoned oil wells and test wells	I	II	I
Brine injection	I	II	I
Disposal wells	I	II	II
Surface impoundments	I	III	I
Mine drainage and mine tailings	II	III	I
Urban and industrial landfills	II	III	II
Radioactive waste disposal	II	III	III
Leaks and spills	II	III	II
Fertilizers and pesticides	II	III	I
Feedlots	II	III	II
Salt-water intrusion	III	III	I
Highway deicing salts	III	III	II
Mass burial of livestock	III	IV	II

a) I - High
II - Moderate
III - Low

b) I - Regional
II - Point source but can be regional in nature due to high density of individual occurrences
III - Can affect adjacent properties
IV - Effluents contained within the boundaries of one property

c) I - Increase
II - No significant change
III - Decrease

as sources of ground-water contamination.

Types of Contaminants

Biological contamination of ground water may occur when human or animal wastes enter an aquifer. Microorganisms present in the wastes may be carried by the ground water into nearby water wells and may cause disease when ingested. Inorganic chemical contamination differs from biological contamination in several important ways. Most important are the indestructibility of inorganic chemicals, the persistence of the pollution created by their presence, and the difficulty in their removal.

The U. S. Public Health Service has specified certain "maximum" concentrations for substances in drinking water (see Appendix). Concentrations of such toxic elements as arsenic and hexavalent chromium greater than 0.05 mg/l would be cause for rejection of the water supply if intended for drinking purposes.

In the arid portion of the Northwest, inorganic chemical contamination is of great concern to agricultural water users. Generally, the quality criteria most often applied relate to total salt concentration (total dissolved solids), chloride, sodium, boron, and bicarbonate. Water low in salts is usually the most desirable for irrigation, but sometimes only water containing several thousand milligrams per liter of salts is available. High evaporation rates and lack of adequate flushing may cause salt accumulation in the root zone with a resulting decrease in crop yields. Reuse and recycling of water for irrigation is a frequent source of salt buildup in both surface and ground water.

Organic chemical contamination is most often caused by such substances as detergents, gasoline, oil, and phenolic compounds. Phosphate contained in detergents and chemical fertilizers may constitute a hazard if present in excessive concentrations in ground water. Gasoline and other hydrocarbons often end up as ground-water contaminants because of leaking tanks, pipeline breaks, or spills at the land surface. The presence of minute concentrations of hydrocarbons may result in abandonment of wells because of objectionable odors and tastes. Frequently, chemical additives complicate the contamination pattern. Phenols present in oil refinery or chemical plant wastes are often found in ground waters. The presence of this contaminant is generally recognized by its taste and odor, which can typically be detected at concentrations as low as 0.001 mg/l (the U. S. Public Health Service recommended limit for phenol in drinking water).

Health Hazards

The types of health problems associated with contaminated water are numerous. The more common health hazards attributed to contaminated ground water are shown in Table 21. The results of a national inventory of waterborne disease outbreaks related to ground-water sources for the period 1946-1970 are shown in Table 22. Contamination at the land surface and overflow or seepage of sewage into improperly constructed wells are the major causes of outbreaks of disease.

Control and Removal of Contaminants

Because of the generally slow rate of movement of ground water, a pollutant may exist for years before the problem is discovered. Contaminating fluids of different densities do not always move with the main body of ground water. They can float near the top of the saturated sediments or sink toward the bottom of the aquifer. Thus, determination of the direction of flow and areal extent of a contaminated ground-water body can be complex, and can be accomplished only by a rather detailed and costly investigation.

Generally, the most common approach to dealing with contaminated ground water is to eliminate the source of pollution as quickly as possible, which is not often feasible. Even if the source of pollution can be removed, the ground-water contamination problem still may not be eliminated because a polluted ground-water body normally moves and disperses slowly.

The degree of reduction in concentration of contaminants with time is related to such factors as the hydraulic properties of the aquifer and recharge conditions. Nevertheless, long after a source of pollution has been removed, it is not uncommon for the contaminated ground-water body to continue expanding in areal extent for many years and travel significant distances before its hazardous effect is minimized. Few studies have been conducted to define the degree to which contaminants will attenuate with time and distance from the source. Some recent modeling investigations simulating variation of ground-water quality with time and distance are expected to assist in the prediction of contaminant movement. 8,9)

Other approaches to the solution of ground-water contamination problems are containment or removal of the pollutant. Containment involves limiting the spread of the pollutant within an affected aquifer. Pumping from wells, installation

Table 21. HEALTH HAZARDS ATTRIBUTABLE TO GROUND-WATER CONTAMINATION 6)

Health Hazards	Nature of Contaminant
Infant Methemoglobinemia	Nitrates usually greater than 45 mg/l
Fluorosis	Fluorides usually greater than 1.5 mg/l
Potential carcinogenic effects	Selenium-concentration unknown
Serious illness or death	Arsenic, cadmium, or lead, usually greater than .05 mg/l
Infectious Hepatitis	Enteric viruses

Table 22. INCIDENCE OF WATERBORNE DISEASE IN THE U.S., 1946-70, DUE TO SOURCE CONTAMINATION: GROUND WATER (UNTREATED) 7/

	Private		Public		All Systems	
Cause	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases
Improper construction or location of well or spring						
Surface contamination nearby	21	640	1	2,500	22	3,140
Overflow or seepage of sewage	49	2,779	4	531	53	3,310
Seepage from abandoned well	1	50	-	-	1	50
Source of contamination not determined	8	235	1	400	9	635
Flooding	4	66	3	4,400	7	4,466
Contamination through creviced limestone or fissured rock	10	555	1	70	11	625
Chemical or pesticide contamination	4	17	-	-	4	17
Data insufficient to classify	46	2,001	3	16,350	49	18,351
Total:	143	6,343	13	24,251	156	30,594

of drains, excavation of affected soils, and artificial recharging are the most common methods used for containment or removal.

Monitoring Ground-Water Quality

Another aspect of ground-water contamination is the problem of monitoring chemical and biological quality. Several factors are responsible for this difficulty, including:

1. The complex nature of aquifer systems and ground-water movement.
2. The variety of potential contamination sources.
3. The frequent lack of baseline data.
4. The economics of establishing a monitoring system.

The complexity of hydrogeologic conditions was indicated in previous paragraphs. In most cases it is necessary to define the extent, thickness, and direction and rate of movement of the polluted body of ground water. This requires test wells and often geophysical surveys. The ground-water quality at various depths below the surface must also be studied. Chemical tracers may have to be introduced into the aquifer to study direction and rate of flow of the ground water. Many wastes are of complex chemical composition, and combinations of different wastes may produce reactions necessitating extensive laboratory work and research to establish the source of pollution.

A significant problem in monitoring ground-water quality is the general lack of baseline data. Usually, no thought is given to a monitoring program until such time as a problem is detected, often too late to establish a meaningful program. Even where water quality baseline data are available, the information is of limited value because many key constituents were not routinely analyzed for in the past. This applies to most of the trace elements such as selenium, molybdenum, and cadmium, and such other toxic metals as lead and zinc.

Finally, the problem of economics influences the establishment of a monitoring program. Federal, state, and often county legislation have pointed to the need for increased surveillance of waste discharge movement. Yet, because of limited funds and personnel, a hazard must be quite severe before a polluter, enforcing agency, or water user assumes the economic burden of establishing a monitoring system.

Certainly the majority of small municipal water-supply companies lack both financing and personnel to routinely establish monitoring programs. Also, most state agencies do not have adequate financial resources or sufficient trained personnel to enforce rigid procedures.

In the following sections, sources of ground-water contamination are discussed in greater detail. Selected case histories on ground-water quality degradation are included to provide a better understanding of the nature of the problems in the Northwest. Locations and references are provided for each of the cases included except where litigation may be pending or where information was provided on a confidential basis.

SEPTIC SYSTEMS

Incidents of ground-water contamination as a result of improper functioning of septic-tank systems are reported in all six states. Contamination can occur under conditions of low permeability of the geologic formation, thin soil cover, high water table, poor well construction, and under-designed waste disposal systems. Table 23 presents an estimate of the population in the Northwest served by septic tanks in 1968. As may be seen, almost three million people, or roughly one third of the entire population in the Northwest, depend on septic tanks for domestic waste disposal.

Perhaps the greatest occurrence of septic tank problems is west of the Cascade Range throughout Washington and Oregon. This is attributed to high annual precipitation, high water tables, and a high population density. Areas where incidents of ground-water contamination are becoming more numerous are along the Front Range of Colorado, and in the expanding suburbs of major cities in Idaho, Wyoming, and Montana. In most instances of contamination from this source, local health departments are aware of the problem and are taking appropriate control measures.

All states and most counties have regulations governing design and installation of septic tanks. Typical requirements are: permit for installation of septic system, minimum lot size, percolation tests and licensing of contractors. 11)

Figure 38 is a diagram of a typical septic tank and soil absorption system. The complete septic tank and tile field system consists of three basic components. The first is the septic tank itself, which is a buried, watertight receptacle designed to remove solids by settlement and to trap and store scum and sludge. The second is the distribution box,

Table 23. ESTIMATED POPULATION SERVED BY SEPTIC TANKS IN 1968. [10)]

State	Estimated population served	Percent of total population
Colorado	84,436 [a)]	4
Idaho	336,130	49
Montana	249,220	37
Oregon	850,708	43
Washington	1,313,410	42
Wyoming	58,195	19
	2,892,099	

a) As of 1970; estimate supplied by Colorado Department of Public Health.

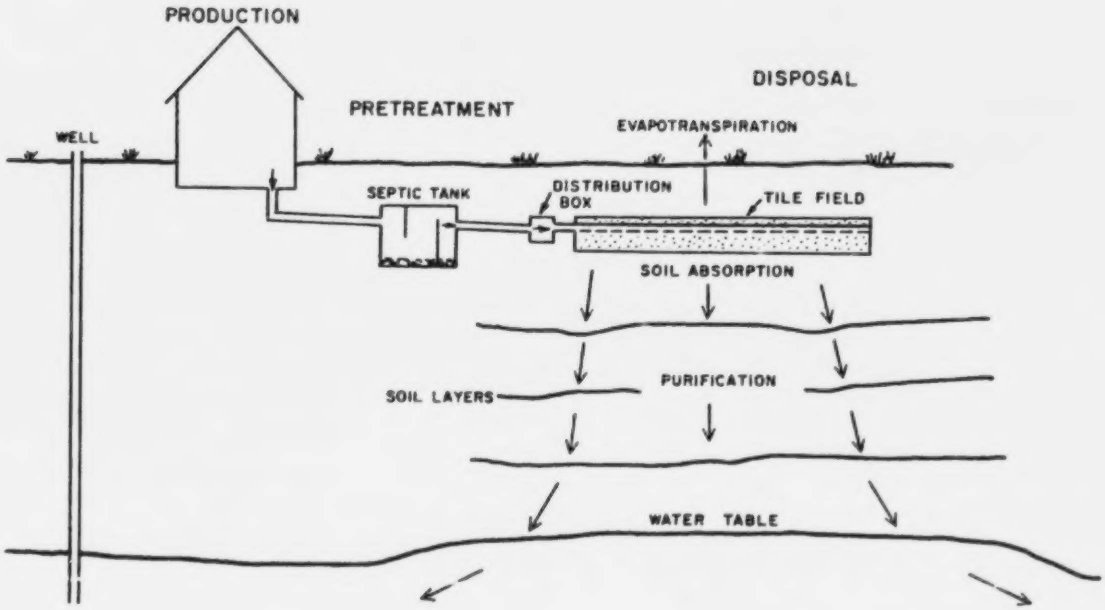

PRODUCTION
DISPOSAL
PRETREATMENT
EVAPOTRANSPIRATION
WELL
SEPTIC TANK
DISTRIBUTION BOX
TILE FIELD
SOIL ABSORPTION
PURIFICATION
SOIL LAYERS
WATER TABLE

Figure 38. Disposal of household wastes through a conventional septic tank and soil absorption system. 12)

which is needed to insure equal distribution of effluent to the several lateral lines of the tile field. The third component is the soil-absorption system or tile field. This consists of a series of pipes, usually made of perforated orangeburg fiber or plastic material, for the purpose of distributing the sewage effluent over an area of soil large enough to absorb it. The distribution lines are normally laid in trenches which are then backfilled with filter material consisting of washed gravel, crushed stone, or slag.

Another similar device commonly used is the dry well or cesspool. This is a large buried chamber with walls of a porous material such as precast, perforated concrete rings or concrete blocks. The size of the chamber varies according to hydraulic loading and other design considerations.

As much as 300 mg/l of total dissolved solids may be added to water by domestic sewage. 12) The effluent from septic tanks can thus increase the concentration of minerals in ground water. Table 24 shows the range of mineral pickup in domestic sewage. Under conditions of normal soil pH, efficient removal of phosphates can take place. Chlorides, nitrates, sulfates, and bicarbonates are not removed and can enter into and move freely within an aquifer. Bacteria and viruses are normally adsorbed onto the soil, but under certain conditions they can reach the water table and can travel significant distances. Some other pollutants associated with septic tanks include synthetic detergents, excessive chlorides from water-softener regeneration, and a number of toxic and non-toxic constituents in special cases where industrial wastes have been discharged to a septic system.

One of the first efforts to use hydrogeologic criteria in land-use planning and in selection of septic tank locations has recently been made by the U. S. Geological Survey. In Whatcom County, Washington, a percolation rate map was prepared based on the physical characteristics of geologic units and the results of percolation tests. 14) Geologic units with rates slower than permeable limits established by the county were separated from those with more rapid rates, thus indicating areas where soil conditions could cause serious problems and even failure in septic tank filter fields.

The principal pollutants found in ground water from septic tank use are nitrates and bacteria. Nitrate as N, in concentrations ranging from 10 to 250 mg/l are believed to cause methemoglobinemia and even death in infants. 6) More recent studies, however, cast some doubt as to whether there

Table 24. NORMAL RANGE OF MINERAL PICKUP IN DOMESTIC SEWAGE. 13)

Mineral	Mineral range (mg/l)
Dissolved solids	100 - 300
Boron (B)	0.1 - 0.4
Sodium (Na)	40 - 70
Potassium (K)	7 - 15
Magnesium (Mg)	3 - 6
Calcium (Ca)	6 - 16
Total Nitrogen (N)	20 - 40
Phosphate (PO_4)	20 - 40
Sulfate (SO_4)	15 - 30
Chloride (Cl)	20 - 50
Alkalinity (as $CaCO_3$)	100 - 150

is significant correlation between nitrate in water and methemoglobinemia irregularities. 15,16)

It is known that bacteria do not travel very great distances when discharged into fine-grained soils of sufficient thickness to filter them out (see Table 25). Observed distances traveled are generally less than 30 m (100 ft).

In fractured rock the situation is different. Bacteria can move significant distances through fractured crystalline rock. Studies in mountain regions of the project areas indicate that even with moderate percolation rates and large distances between water wells and conventional waste disposal units, septic tanks pose a threat to ground-water quality. Principal findings of one study carried out in the foothills of the Rocky Mountains are as follows: 18)

1. Bedrock fractures readily accept and convey contaminated percolating waters to shallow ground-water supplies.

2. The direction and rate of movement of bacteria-laden effluent is largely affected by the character and direction of the bedrock fracture patterns.

3. Insufficient microbial filtration of leach-field effluent occurs in or along fractures and joints in crystalline rocks.

4. The horizontal distances traversed by percolating effluent through fractured bedrock often exceed 30 m (100 ft), and may exceed several hundred feet.

As most mountain communities and homesites in the Northwest rely on individual wells or springs for their water supply and on individual septic systems for domestic waste disposal, contamination of ground water is a distinct possibility. This is particularly true in upland regions underlain by crystalline rock. A cross section of a typical mountain setting for domestic wells and septic systems depicting possible movement of contaminants is shown on Figure 39. All too frequently, the commonly held belief that a water supply is safe if a leach field is downslope, does not hold true. What is overlooked is that the bottom of the well may be at the same elevation as the leach field, and that pumping a well may change the direction of ground-water movement in the area.

Case Histories

As stated earlier, septic-tank effluent contamination fre-

Table 25. MOVEMENT OF BACTERIA THROUGH POROUS MEDIA. 17)

Source of pollution	Pollution indicator	Observed distance travelled	
		Meters	Feet
Sewage polluted trenches intersecting ground water	Coliform bacteria	20	65
Sewage in bored latrines intersecting ground water	Anaerobic bacteria	15	50
	Coliform bacteria	3	10
Sewage in bored latrines lined with fine soil	Coliform bacteria	3	10
Sewage polluted ground water	Bacteria	A few meters	

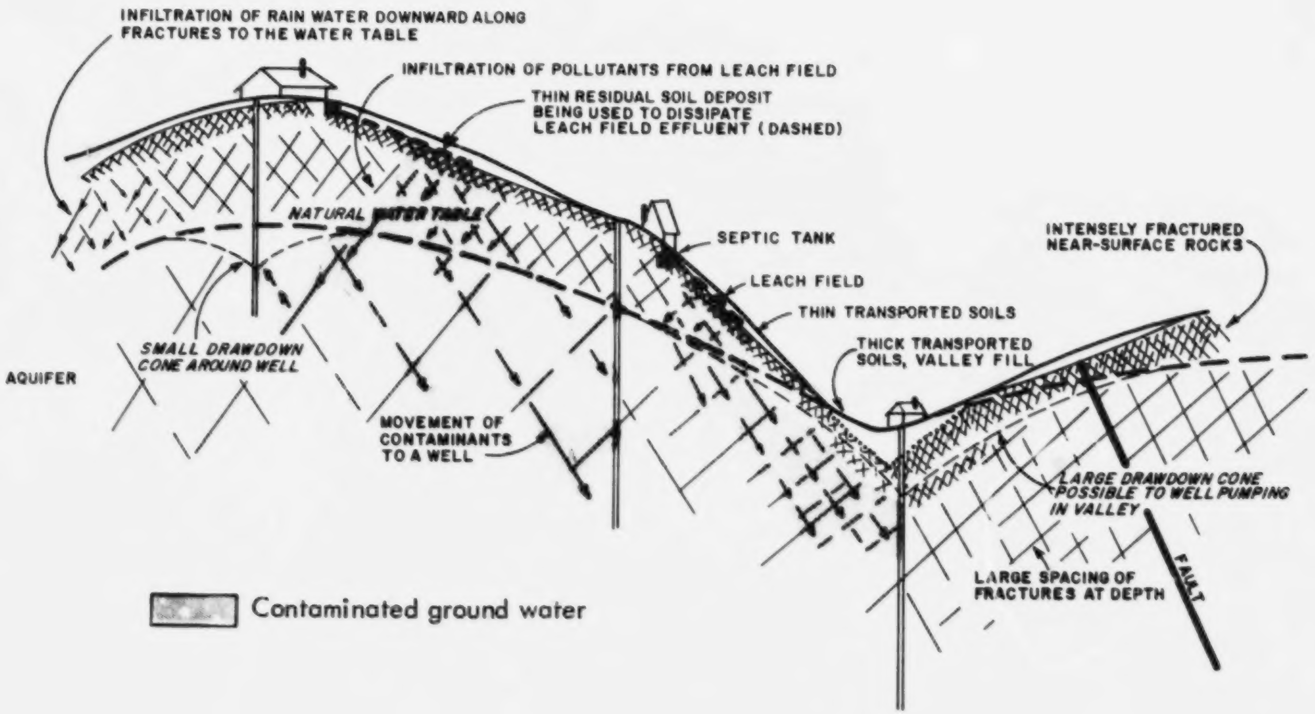

INFILTRATION OF RAIN WATER DOWNWARD ALONG FRACTURES TO THE WATER TABLE
INFILTRATION OF POLLUTANTS FROM LEACH FIELD
THIN RESIDUAL SOIL DEPOSIT BEING USED TO DISSIPATE LEACH FIELD EFFLUENT (DASHED)
NATURAL WATER TABLE
SEPTIC TANK
LEACH FIELD
THIN TRANSPORTED SOILS
THICK TRANSPORTED SOILS, VALLEY FILL
INTENSELY FRACTURED NEAR-SURFACE ROCKS
SMALL DRAWDOWN CONE AROUND WELL
AQUIFER
MOVEMENT OF CONTAMINANTS TO A WELL
LARGE DRAWDOWN CONE POSSIBLE TO WELL PUMPING IN VALLEY
LARGE SPACING OF FRACTURES AT DEPTH
FAULT
Contaminated ground water

Figure 39. A cross-section of a typical mountain setting for domestic wells and septic systems on thin soils and a fractured rock aquifer. 19)

quently occurs in areas with relatively thin soil cover. These conditions are found along the Front Range of Colorado, and in most mountainous areas of the Northwest.

A quantitative study of mountain homesites in the Red Feather Lakes area of north-central Colorado was made in which geologic, topographic, and hydrologic variables were considered in order to determine conditions likely to cause pollution of ground water. 20) Of a total of 85 mountain homesites with individual wells, 62 percent of the wells were found to be contaminated by coliform bacteria. The position of wells in this area relative to bedrock fracture orientations and leach fields accounted for the high incidence of pollution. The study confirmed that orientation of joints in the bedrock significantly affects the travel paths of contaminants, and that detailed studies of geologic structure can be used to evaluate the pollution potential at a site.

Ground-water contamination from septic tank effluent in urban or suburban areas is reported in all six states. High bacteria counts and high nitrates in wells serving a community of 200 residents in Colorado were traced to shallow and improperly constructed wells that were located in close proximity to watercourses. 21)

Septic tank effluent has contributed significant amounts of ABS (alkyl benzene sulfonate - a detergent) to water-table aquifers in the South Platte River basin in Colorado. 22,23) Although ABS itself is not considered to be toxic, its taste and foaming appearance are regarded as problems and do affect the ultimate usefulness of the aquifer. ABS in ground water points to the possible presence of other harmful contaminants from liquid wastes. Areas thus affected were the suburbs east of the city of Boulder and in or near the towns of Wellington, Nunn, Pierce, Eaton, Severance, Hereford, and Merino. ABS was also detected in water from domestic wells near the city of Estes Park, located in the Front Range mountains. In the Denver area, ABS derived from septic tank effluents was observed in shallow domestic wells in the suburban areas of Adams City, Derby, and Irondale, and in the rural area bounded by Brighton, Barr Lake, and Henderson.

In Idaho, some ground-water contamination from septic tanks has occurred in the shallow aquifer near Boise. Fortunately, this aquifer is not used for drinking water supplies. 24) Problems are also reported from several other communities. 25,26)

In Montana, some problems with septic tank effluent and well water have been reported in the Kalispell and Helena areas.

Coliform bacteria and high nitrates have been reported in water from wells in the town of Livingston located along the Yellowstone River. 27) Out of 17 county sanitarians contacted during this investigation, 13 reported problems of septic effluent in their respective counties, and two others expressed concern about potential contamination and cited the need for additional investigation. 28)

One community in Lincoln County with a population of about 2,000 has had some severe problems. The town is on a floodplain and nearly every dwelling is served by its own well and septic system. Each spring, with rising water-table conditions, an increase in coliform bacteria is noted in water wells, indicating fecal pollution. In the period 1962-63, 150 hepatitis cases were reported in this community. 29)

In Oregon, high nitrates resulting from septic tank effluent are present in the unconsolidated aquifer in the Eugene area. Nitrate concentrations in ground water range up to 100 mg/l in this and several other areas of the state. 30,31, 32)

In Washington, suburban developments in several areas have experienced contamination of ground water from septic tank fluids. 33,34) Problems have been reported in the Nooksack Valley in Whatcom County and the town of Snohomish. In the latter community, of 100 domestic wells, 50 are contaminated. Many unsewered housing developments in the Tacoma-Seattle area are built adjacent to lakes, and ground water mixed with septic effluent discharges into these bodies of water and causes pollution (e.g., Lakes Steilacoon, Washington, and Sammamish). Many lakes have to be periodically cleaned and flushed to allow swimming.

A new shoreline management law enacted in the state of Washington in 1972 requires buffer zones along lakes and shorelines. Development within such buffer zones must be approved by local or county agencies. Although some benefit may be derived from such zones it is doubtful that, over the long term, buffer zones will be effective in controlling discharge of contaminated ground water to these lakes.

In the Vancouver metropolitan area (Clark County), several hundred homes have septic tanks and rely on shallow individual wells for water supply. Several problems of contamination are reported. 34) This situation is watched very carefully, as the Vancouver well field is directly downgradient from these housing developments.

Urban expansion and reliance on individual wells and septic tanks is causing concern for ground-water contamination in the West Valley area of Yakima County. During the summer months, ground-water levels in the valley rise to a point where proper treatment of sewage cannot take place in the unsaturated zone. Samples of 100 private wells indicated bacterial contamination in 23 wells. 35) In Wyoming, local problems of ground-water contamination from septic tanks are reported in the Cheyenne area and in several communities in the Bighorn Basin. 36)

SEWAGE TREATMENT PLANT DISCHARGE

As of 1968, 875 sewage treatment plants served 6.4 million people or two-thirds of the total population in the six states (Table 26). In the arid zone of the Northwest, discharge of effluent from sewage treatment plants presents a potential hazard to ground-water quality. Treated effluent is discharged directly to rivers or streams, or else it is put into lagoons or basins. Discharge of effluent to ground water from leaking lagoons is discussed in greater detail in the section "surface impoundments".

In the Plains, most unconsolidated aquifers are in direct hydraulic connection with the rivers, and pumpage from wells in the valleys induces surface water to enter the aquifer. During high flow periods, sewage effluent discharged to rivers is diluted, but during the rest of the year stream flow is almost entirely base flow and dilution of wastes is minimal except in major rivers. It is at this time that irrigation water requirements are at their peak, and ground-water pumpage is at a maximum.

The effluent discharged by sewage treatment plants contains chemicals and minerals that cannot be removed by normal sewage treatment processes. Furthermore, overloading of treatment plants or poor maintenance can result in the discharge of only partially treated sewage to surface-water bodies.

Case Histories

Widespread ground-water contamination due to discharge from sewage treatment plants has occurred in the Denver area. 22, 23) In 1965, a total of 23 plants discharged about 400,000 cu m/d (105 mgd) in the South Platte River basin. In 1974, 530,000 cu m (140 million gallons) of sewage effluent was discharged daily, 40 percent in excess of plant capacity. 38) Studies made in 1965 and 1967 indicated that sewage plant effluent contributed ABS detergents and nitrates to the valley-fill aquifer, mainly between Denver and Kersey. The valley-fill aquifer is the principal source of water for the

Table 26. NUMBER OF SEWAGE TREATMENT PLANTS AND POPULATION SERVED IN 1968. 37)

State	Number of Plants	Population Served
Colorado	204	2,413,203
Idaho	93	348,880
Montana	125	436,180
Oregon	167	1,102,642
Washington	208	1,798,525
Wyoming	78	255,050
Total:	875	6,354,480

majority of the public water systems. Numerous individual and 13 municipal wells reported the presence of ABS in water. Although ABS-type detergents are no longer manufactured, ABS pollution of ground water is expected to persist for several decades. Amounts of nitrate contributed to the aquifer from sewage-laden waters diverted for irrigation use were believed to be very significant.

Serious pollution problems in shallow valley-fill aquifers as a result of insufficient dilution of sewage effluent are also reported in the Tualatin Valley in Oregon. Stream flow decreases from 566 cu m/s (20,000 cfs) in winter to almost zero in the summer time. 39)

IRRIGATION RETURN FLOW

Large land areas totaling 6.3 million ha (15.5 million acres) are under irrigation within the project area. The distribution of irrigated areas in the six states is shown on Figure 40. Approximately half of this irrigated land is in the states of Colorado and Idaho (see Table 27). Principal centers of irrigation are the San Luis Valley, the Platte and Arkansas River valleys, the High Plains of Colorado, the Snake River Plain and the Columbia Plateau. Practically all (90 percent) of the water used for irrigation comes from rivers and streams. Total ground-water use for irrigation is about 20,000 cu m/d (5,200 mgd), most of which is pumped in Colorado and Idaho.

Contamination of ground water often stems from return flow, which is irrigation water that finds its way back into the aquifer and includes by-pass water, seepage, deep percolation, and tail-water runoff. Irrigation water contains variable quantities of dissolved salts, and these dissolved constituents may undergo great changes in concentration and composition as a result of irrigation operations. Plants take water from the soil and transpire it to the atmosphere but take up very little salt from irrigation water. The net result of evapotranspiration is to remove a large part of the soil water leaving the salts behind in the root zone. In irrigated areas where inadequate leaching and drainage occur, the soil may become saline and unproductive. Excess irrigation water often leaches salts from the root zone into the shallow aquifer and frequently this saline ground water then rises into the root zone. Successful irrigation in such areas hinges on the proper drainage and removal of saline water to a receiving stream.

Studies by Law and others in Oklahoma showed that drainage waters from irrigated areas adversely affected both surface-

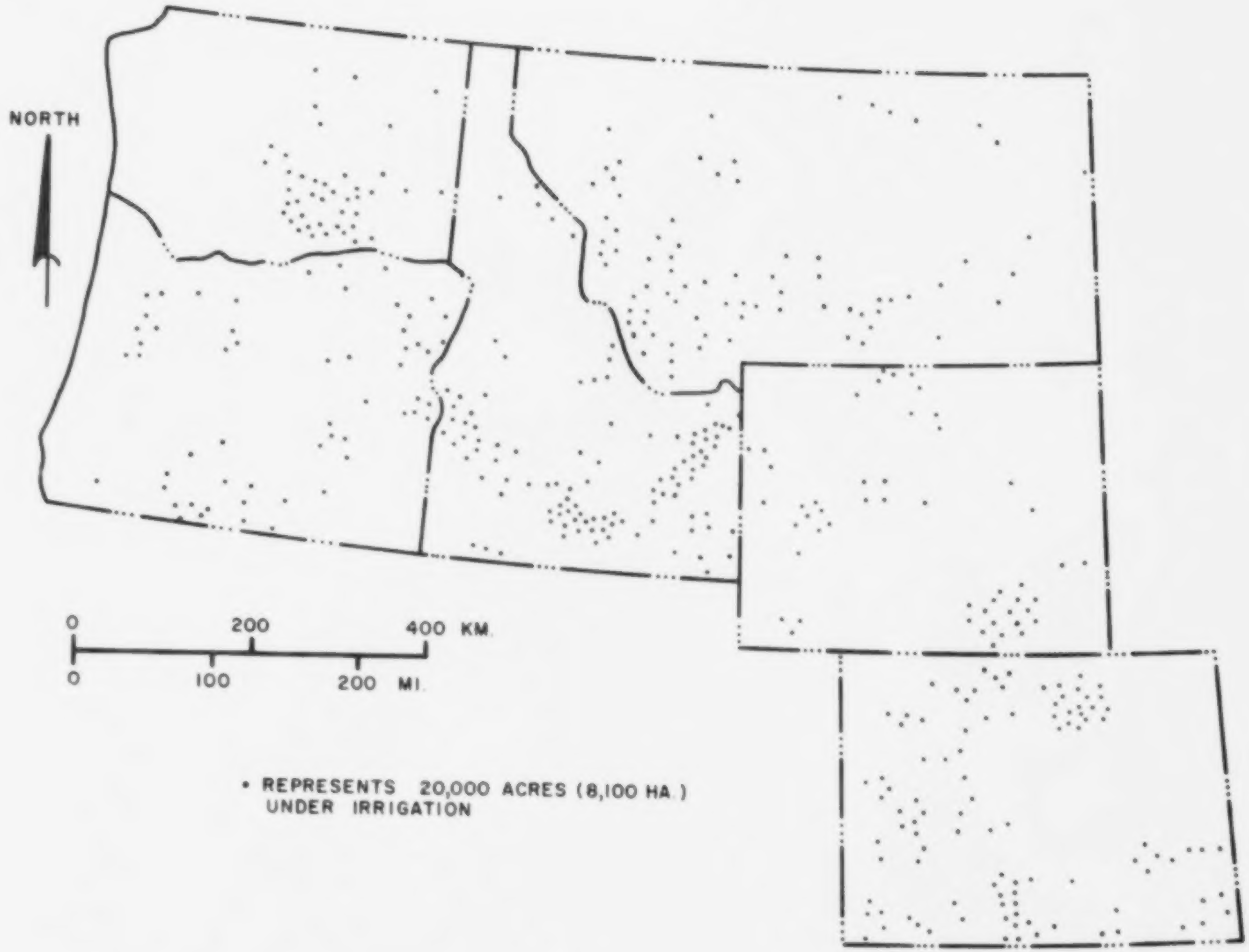

NORTH
0
200
400 KM.
0
100
200 MI.
• REPRESENTS 20,000 ACRES (8,100 HA.)
UNDER IRRIGATION

Figure 40. Distribution of irrigated areas in the Northwest.[40]

Table 27. IRRIGATED LAND AREAS IN 1970. [41)]

State	Irrigated land	
	Hectares	Acres
Colorado	1,862,000	4,600,000
Idaho	1,497,000	3,700,000
Montana	890,000	2,200,000
Oregon	768,000	1,900,000
Washington	566,000	1,400,000
Wyoming	687,000	1,700,000
Total	6,270,000	15,500,000

and ground-water resources. Compared with the quality of irrigation water applied, surface-water return flow showed an increase of about 20 percent in total dissolved solids content, and percolating soil water showed a five to eightfold increase over the salinity of the applied water. 42)

The status and extent of saline areas in the six states as of 1960 is shown in Table 28. At that time about 840,000 ha (2 million acres) were affected by salinity. Almost 50 percent of the saline land was in Colorado.

Case Histories

Degradation of surface water due to irrigation returns has been studied by Eldridge, who reported on the Yakima River and the Sunnyside Irrigation District in Washington, the Boise River in Idaho, and the upper Colorado, Arkansas and Upper Columbia River basins. 44) Other salinity studies have been carried out in the Grand Valley and the South Platte River basin in Colorado and in Rosebud County in Montana. 45,46,47)

In the Grand Valley of western Colorado, irrigation is contributing large salt loads to the Colorado River. Seepage and deep percolation losses to the saline soils and aquifers and the eventual return of these saline flows to the river system make the Grand Valley a significant source of salinity in the Upper Colorado River basin. It is estimated that return flows in the valley are responsible for 37 percent of the total salt load in the basin. 43)

Pickup of salts results from percolating water coming in contact with the naturally saline soils and aquifers overlying the Mancos Shale bedrock. The shale, which is also the origin of many of the soils, contains lenses of salt that are readily dissolved. Irrigation canal seepage and excess irrigation water move downward to the water table and travel to the Colorado River (see Figure 41).

Salt budget studies by Skogerboe indicated that each hectare under irrigation contributes about 27 metric tons of salt to the valley-wide salt pickup. A projection of this figure over the entire valley, assuming 28,000 ha of irrigated land, indicates an annual salt discharge to the Colorado River of 700,000 to 800,000 metric tons. 43) Numerous years of research in the valley have been conducted in an effort to determine the hydrochemical processes controlling salt-load pickup. One remedy involves reducing the flow of water into the ground-water system, which can be accomplished by lining irrigation canals and improving on-farm water management.

Table 28. LAND AREAS AFFECTED BY SALINITY IN 1960 43)

State	Land area reported	Total land area Hectares 1,000	Total land area Acres 1,000	Saline land area Hectares 1,000	Saline land area Acres 1,000	Percent
Colorado	Statewide	1,138	2,812	397	982	34.9
Idaho	All but 3 counties	761	1,880	102	253	13.5
Montana	4 areas	503	1,243	80	197	15.9
Oregon	Statewide	603	1,490	42	103	6.9
Washington	23 counties and Columbia Basin	899	2,221	108	266	12.0
Wyoming	Statewide	510	1,261	113	280	22.2
	Total:	4,414	10,907	842	2,081	19

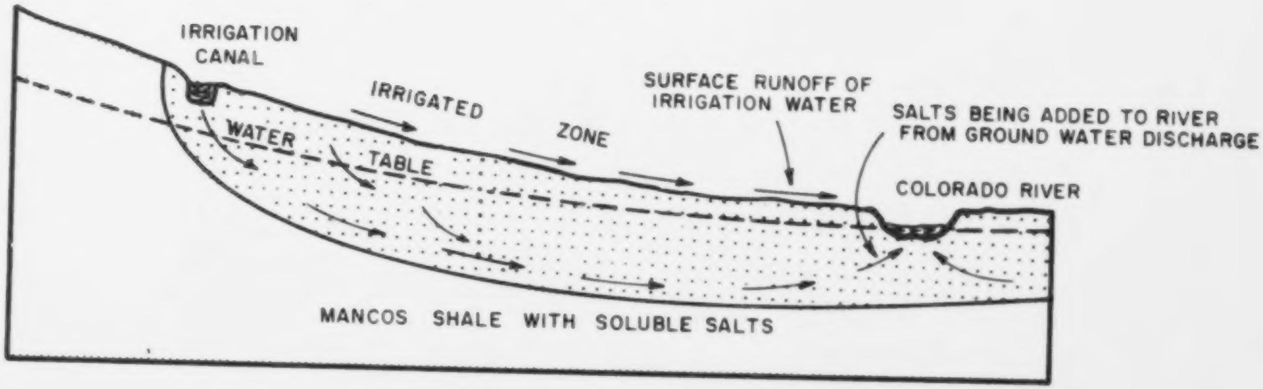

IRRIGATION CANAL
IRRIGATED ZONE
WATER TABLE
SURFACE RUNOFF OF IRRIGATION WATER
SALTS BEING ADDED TO RIVER FROM GROUND WATER DISCHARGE
COLORADO RIVER
MANCOS SHALE WITH SOLUBLE SALTS

Figure 41. Cross section of Grand Valley of Colorado illustrating salt pickup from irrigated lands. 48)

In the heavily irrigated South Platte Valley, increased mineralization as a result of irrigation is a common problem. Studies have shown that the same water is used either as surface or ground water as many as seven times in the 65-mile stretch from Denver to Kuner, and mineralization in ground water often increases in a down-valley or downgradient direction. 49) An intensive study of water quality and pollution in the valley was made by the Environmental Protection Agency in 1971-72. 46) Because of the various sources of degradation, man-made and natural, it is rather difficult to ascertain what percentage of contamination problems is a direct result of irrigation return flow.

In the Arkansas River valley, the salt buildup in water from the unconsolidated aquifer is approaching concentrations greater than crop tolerance limits, and use of water from many wells is restricted more by quality than quantity. The relationship between irrigation practices and water quality variations is extremely complex. Figure 42 shows an idealized block diagram of the stream-aquifer system as it relates to water quality. Model simulation of the stream-aquifer system and changes in flow and salinity appears to be a promising water management tool. The first study of this kind was recently carried out in the Arkansas River valley between La Junta and the Bent-Otero County line. 8)

In the Yakima region of Washington, approximately 160,000 ha (400,000 acres) of land were under irrigation in 1971 for various crops. Water in the Yakima River was found to be affected by irrigation runoff and discharge of poor quality ground water. 43)

Another recorded instance of contamination is in the area of Odessa in Washington. Several shallow domestic wells were taken out of service as a result of contamination by irrigation return waters. 43) Some domestic wells in Snohomish County, Washington, yield water high in nitrates, believed to be a result of infiltration of water from irrigated land. 50) High nitrates encountered in some irrigation wells in Laramie County, Wyoming, are believed to have been caused by irrigation return flow. 51) Cattle in Rosebud County, Montana, refuse to drink the highly mineralized water from shallow alluvial wells affected by irrigation return flow. 47)

In the Snake River valley, three million acres of land are presently being irrigated. 43) However, poor quality water that may be related to intensive irrigation has been noted in only a few areas. Potential ground-water quality problems could result if an additional five million acres of

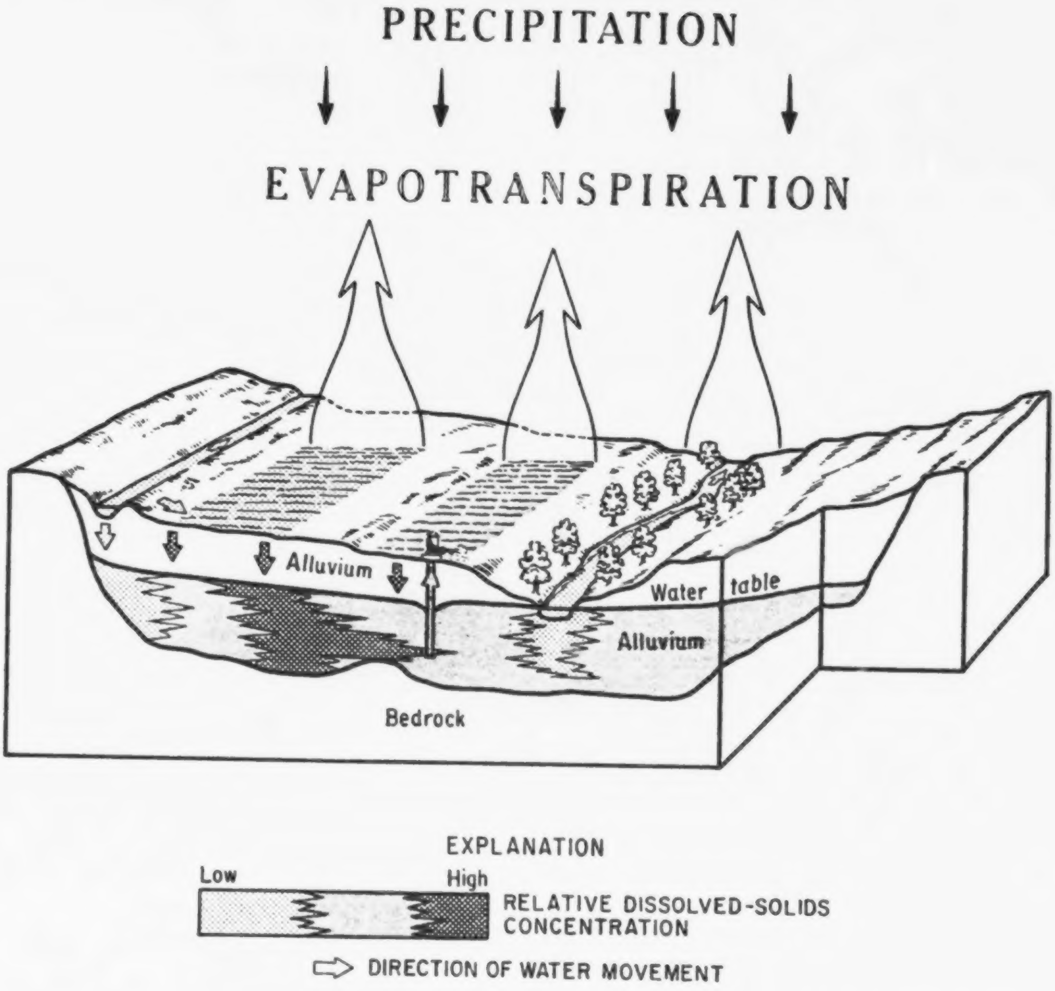

PRECIPITATION
EVAPOTRANSPIRATION
Alluvium
Water table
Alluvium
Bedrock
EXPLANATION
Low
High
RELATIVE DISSOLVED-SOLIDS CONCENTRATION
DIRECTION OF WATER MOVEMENT

Figure 42. Idealized block diagram of part of the Arkansas River Valley illustrating variable ground-water quality. 8)

irrigable land were to be developed. At present, sufficient dilution takes place in the aquifer to decrease the salinity to tolerable limits. However, a study made on one tract of some 80,000 ha (202,000 acres) showed that the concentration of soluble salts in ground water was more than twice that of the applied surface water, and the potential for salinity buildup would be greater in areas where ground water is the source of applied irrigation water. 52,53)

A study of the quality of irrigation waters and subsurface drainage in Boise Valley showed that nitrate losses to percolating water varies widely with type of crop and fertilization practices. The amounts of nitrate lost to ground water from sugar beet and onion fields were 2.156 lb/acre and 15.188 lb/acre respectively or roughly 2.5 kg/ha and 17.5 kg/ha. 54)

Excessive concentrations of nitrate in ground water in the Lower Columbia River basin and in the area of Twin Falls, Idaho, have been attributed to irrigation return flows. 43)

DRYLAND FARMING

Dryland farming on the northern Great Plains appears to be the principal cause of extensive saline-seep problems affecting large areas of farm land. According to Marvin R. Miller of the Montana Bureau of Mines and Geology, the saline-seep problem stems both from the geology of the region and the crop-fallow dryland farming system now in use. 55,56) Favorable conditions for development of saline seeps exist where glacial till, an unstratified, heterogeneous mixture of clay, sand, gravel and boulders deposited during glaciation, is underlain by a thick, impermeable shale. Excess water moving through the soil and glacial till builds up on top of the underlying impermeable shale, forming a "perched" water table. This excess water gradually moves downslope and eventually reaches the land surface, where it evaporates, leaving the dissolved salts behind. The water is strongly saline because of a large supply of natural soluble salts contained in the subsoil, glacial till, and shale. A cross section of a typical saline-seep situation in northern Montana is shown on Figure 43.

Much of the saline water evaporates before reaching perennial streams, leaving the salts behind to be flushed during spring runoff. Calculations of salt accumulation made by U. S. Agricultural Research Service scientists show that large amounts of salt are deposited in seep areas. Assuming a salt concentration in seep water of 13,000 mg/l and 25 mm (one in) of rainfall on a 4 ha (10 acre) area percolating to

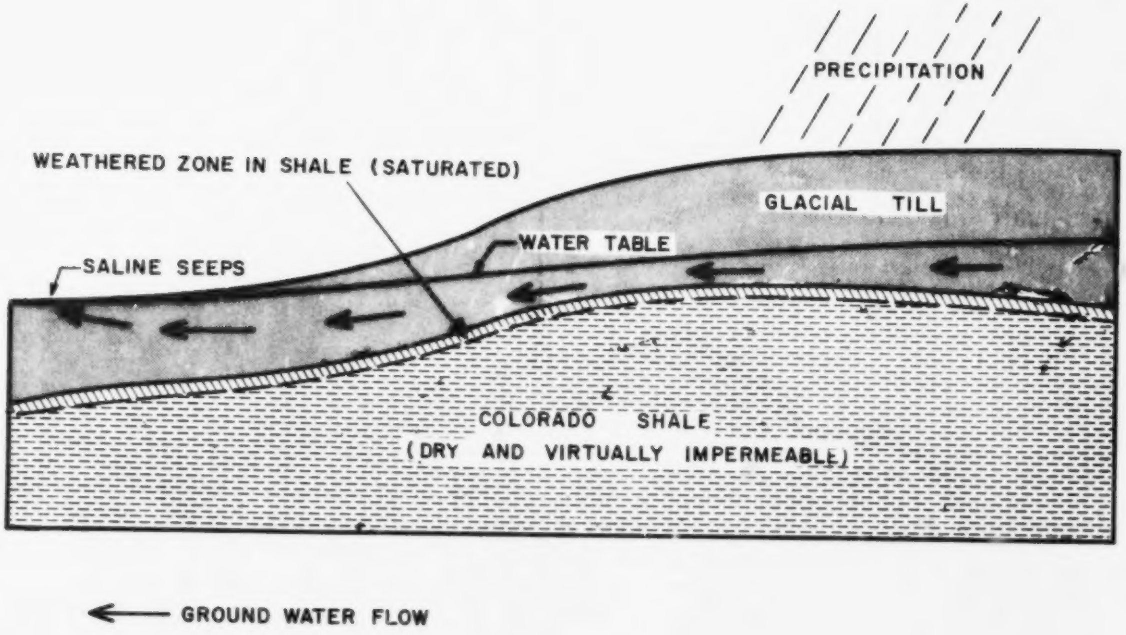

PRECIPITATION
WEATHERED ZONE IN SHALE (SATURATED)
GLACIAL TILL
WATER TABLE
SALINE SEEPS
COLORADO SHALE
(DRY AND VIRTUALLY IMPERMEABLE)
GROUND WATER FLOW

Figure 43. Cross section of a typical saline-seep area in northern Montana. 55)

an impermeable clay zone; and assuming that all this ground water was channeled into a seep area of 0.4 ha (one acre), 13.4 metric tons (14.7 tons) of salt would remain in the seep area after the water evaporated. 57)

Chemical analyses of saline-seep water from the Fort Benton area in Montana are shown on Table 29. Seep water in this area commonly contains more than 25,000 mg/l of total dissolved solids. Predominant dissolved constituents in the ground water are sodium, magnesium, sulfate, and nitrate. High concentrations of trace metals, namely, aluminum, iron, manganese, strontium, lead, copper, zinc, nickel, chromium, molybdenum, selenium, and vanadium were found to be present in the water.

Saline seeps are becoming a regional problem and are now under investigation by several agencies, including the Montana Bureau of Mines and Geology, the U. S. Department of Agriculture, the Montana Department of Health & Environmental Services, and the Montana Agricultural Experiment Station. As of 1971, in Montana alone, over 32,000 ha (80,000 acres) of cropland had been lost to saline seeps. Since then, an estimated additional 40,000 to 60,000 ha (100,000 to 150,000 acres) have been affected. The loss in farm income due to saline seeps is five million dollars per year.

Geological conditions favorable to saline-seep development are similar over vast areas of Montana (32,400 sq km or 12,500 sq mi), North and South Dakota (118,000 sq km or 45,500 sq mi), and the prairie provinces of Canada (181,000 sq km or 70,000 sq mi). Saline seeps are also spreading over an area of 11,700 sq km (4,500 sq mi) in Montana, underlain by siltstone, sandstone, shale, and coal of the Fort Union Formation. Dryland farming regions and the area of potential saline-seep development in Montana are shown on Figure 44.

Interestingly, the saline-seep problem appears to be a direct result of man's farming activities. Prior to settlement, the natural vegetation on the Plains consisted of buffalo grass which consumed relatively large quantities of water and left no surplus for deep percolation. Present crop-fallow farming practices, good weed control, stubble-mulching, and wind barriers have reduced evapotranspiration losses and more water moves down below the root system.

Field investigations involving drilling of test holes to monitor ground-water levels and water quality indicate that cropping of susceptible areas more frequently and permitting less land to go idle during the summer will reduce the

Table 29. CHEMICAL ANALYSES OF SALINE SEEP WATER FROM THE FORT BENTON AREA, MONTANA. 55)

(All values are in mg/l, except as indicated)

Parameter	Well BF2	Well HA2
Calcium (Ca)	31	21
Magnesium (Mg)	4,000	1,270
Sodium (Na)	6,220	3,500
Iron (Fe)	.17	.07
Manganese (Mn)	.17	.06
Aluminum (Al)	.42	.20
Lead (Pb)	1.15	.64
Copper (Cu)	.13	.04
Zinc (Zn)	.22	.09
Nickel (Ni)	.55	.21
Silver (Ag)	.08	.04
Bicarbonate (HCO_3)	241	248
Carbonate (CO_3)	0	12
Sulfate (SO_4)	29,700	13,435
Chloride (Cl)	257	282
Nitrate (NO_3)	630	33
Fluoride (F)	.9	0
Silica (SiO_2)	10.0	5.5
Specific conductance (micromhos)	34,000	18,600
pH	8.29	8.49

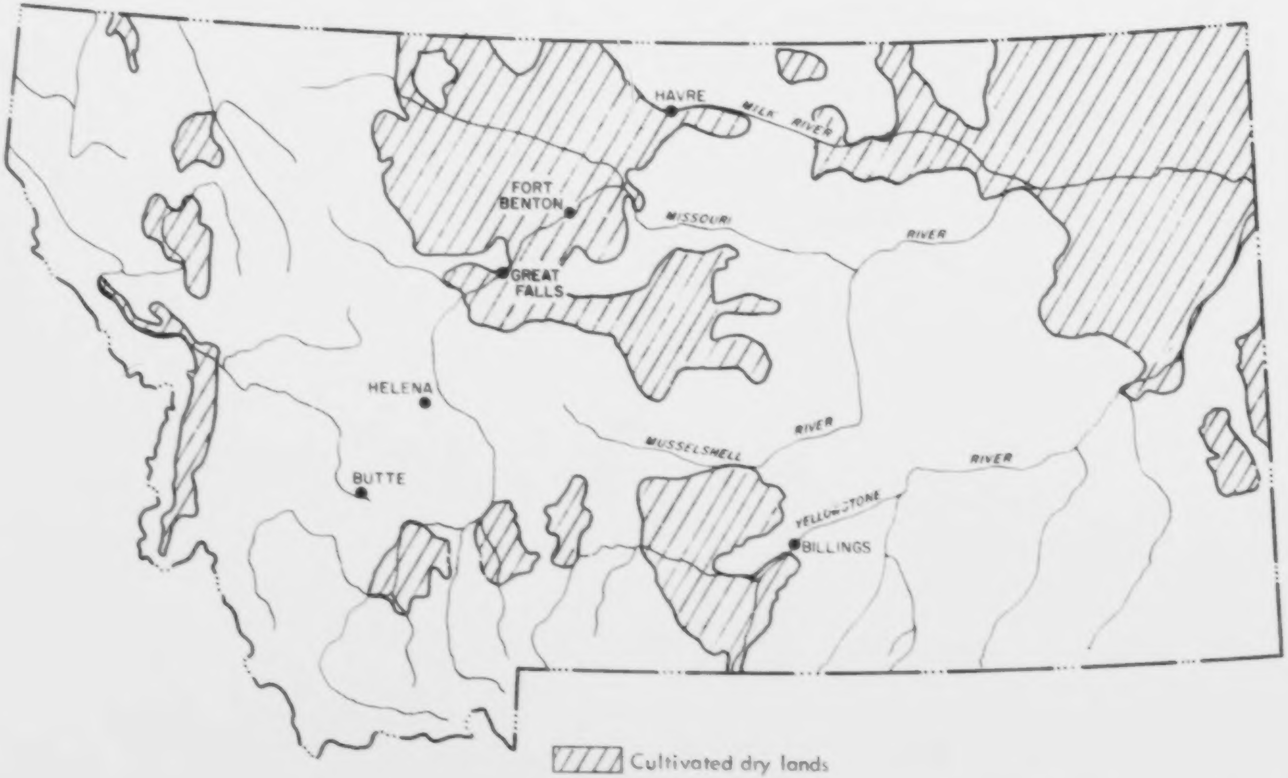

HAVRE
MILK RIVER
FORT BENTON
MISSOURI
RIVER
GREAT FALLS
HELENA
BUTTE
MUSSELSHELL
RIVER
YELLOWSTONE
RIVER
BILLINGS
▨ Cultivated dry lands

Figure 44. Dryland farming and area of potential saline-seep development in Montana. 55)

chances of development of more seeps and retard the increase in size of existing ones. Research studies are now aimed at reducing risks involved in changing crop patterns. It appears that only a change in farming practices will be effective in controlling this type of degradation of ground-water quality.

ABANDONED OIL WELLS AND TEST WELLS

Production of oil and gas is an important economic activity in the Northwest. Together, the states of Colorado, Montana, and Wyoming produce about 7 percent of the crude oil in the nation. Total annual production of crude is some 32 million cu m (200 million barrels). Crude oil production by state is shown in Table 30. Wyoming is by far the largest producer of oil and accounts for 70 percent of the total production of the three states. This oil is produced from several hundred oil fields located primarily in the Denver Basin of Colorado, the Laramie, Hanna, Wind River, Green River, Powder River, and Bighorn Basins in Wyoming, and the Powder River, Williston Basin, and Sweetgrass Arch area of Montana (Figure 45).

Several thousand exploratory and development wells are drilled by the oil industry each year, and of these more than 1,000 unsuccessful wells are plugged and abandoned (see Table 31). In addition, prior to or during exploration for petroleum, natural gas, and other mineral deposits, numerous small-diameter holes are drilled to obtain samples of subsurface formations or to serve as shot holes for seismic surveys. In the oil and gas regions of Montana, Wyoming, and Colorado, thousands of these holes have been drilled. Most holes range in depth from 3 to 120 m (10 to 400 ft) and average 60 m (200 ft). Many of these holes intersect one or several water-bearing formations. Many officials interviewed expressed considerable concern about potential ground-water pollution from interflow conditions between multiple aquifers as a result of hydraulic head differentials in inadequately plugged wells and test holes. Recent legislation in Colorado, Wyoming, and Montana describes procedures for abandoning and sealing of wells and test holes, but enforcement is lacking.

Case Histories

Problems of hydrogen sulfide gas and poor quality water leaking into fresh-water aquifers are reported in the Bighorn Basin of Wyoming. This contamination is due to improperly constructed oil wells, leaky casing or improper cementing. The situation is especially bad in the area east and north

Table 30. CRUDE OIL PRODUCTION IN THE NORTHWEST. [58,59,60]

State	Year	Quantity of Crude Oil Produced Cubic meters	Barrels [1]
Colorado	1971	4,355,000	27,391,000
Montana	1971	5,501,000	34,599,000
Wyoming	1972	22,259,000	140,011,000

[1] One barrel is 42 gallons.

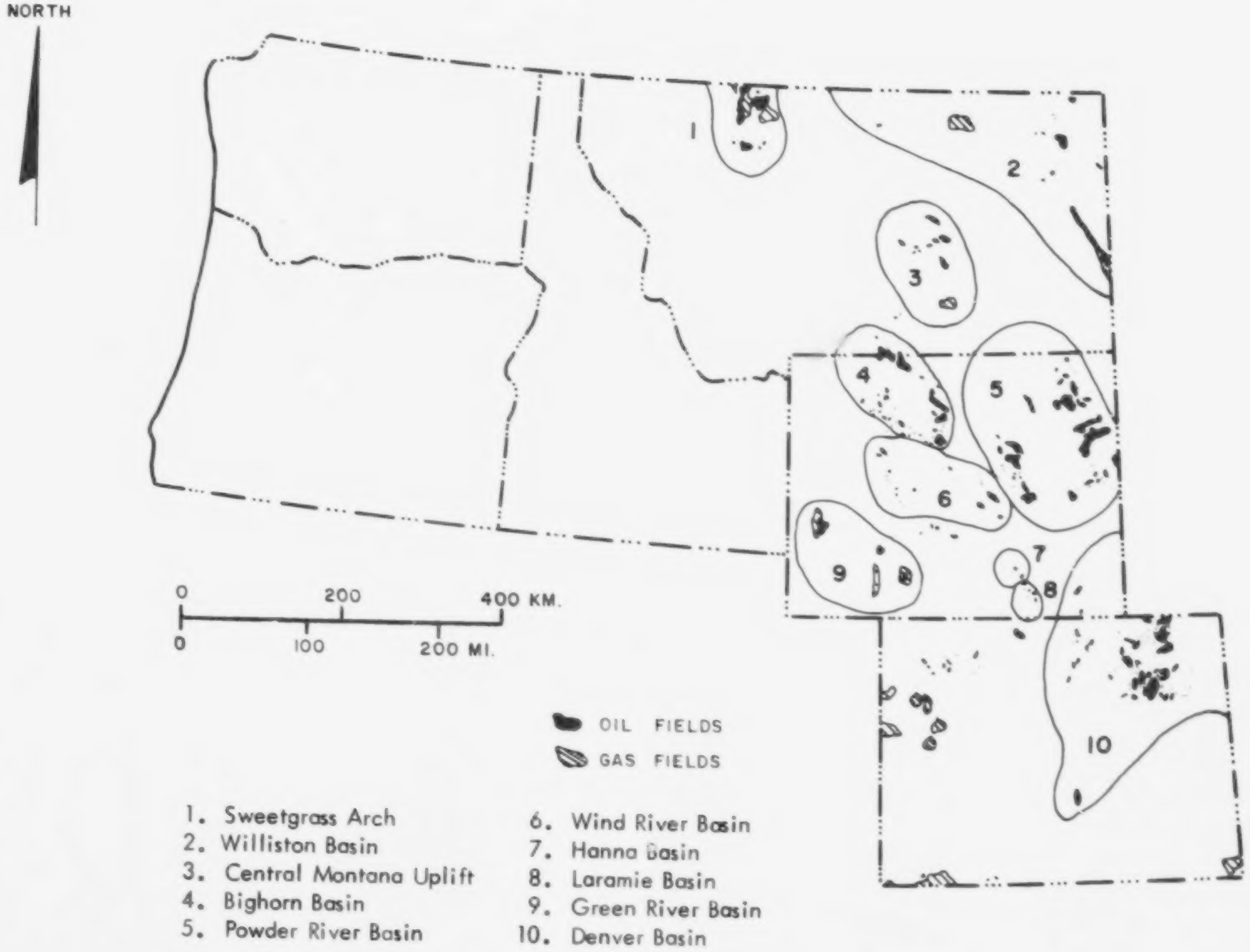

NORTH
0
200
400 KM.
0
100
200 MI.
OIL FIELDS
GAS FIELDS
1
2
3
4
5
6
7
8
9
10
1. Sweetgrass Arch
2. Williston Basin
3. Central Montana Uplift
4. Bighorn Basin
5. Powder River Basin
6. Wind River Basin
7. Hanna Basin
8. Laramie Basin
9. Green River Basin
10. Denver Basin

Figure 45. Principal oil and gas fields in the Northwest. 61)

Table 31. OIL AND GAS DRILLING ACTIVITY, 1971-72.[62,63,64]

	Oil Wells	Gas Wells	Plugged and Abandoned Wells	Total Wells
Exploratory Wells				
Colorado (1972)	28	18	325	371
Montana (1971)	4	16	283	303
Oregon (1971)	0	0	1	1
Washington (1971)	0	0	0	0
Wyoming (1971)	33	10	302	345
Development Wells				
Colorado (1972)	252	119	205	576
Montana (1971)	41	17	66	124
Oregon (1971)	0	0	0	0
Washington (1971)	0	0	0	0
Wyoming (1971)	372	33	143	548

of Worland. 36)

Concern has also been expressed about the practice of pulling old casings in order to reuse them for exploratory drilling. It appears that some operators cannot obtain the necessary steel pipe because of the present steel shortage and resort to pulling out old well casings without taking proper steps to seal or plug these holes.

A classic example of problems that can arise from abandoned wells has occurred in Colorado. 65) In 1915, an oil test hole was drilled in west-central Colorado to a depth of 560 m (1,837 ft). This well encountered warm, mineralized water. Fifty-three years later, on May 9, 1968, the well was found to be discharging 7,338 cu m/d (1,350 gpm) of brackish water with a concentration of 19,200 mg/l dissolved solids. It was estimated that this flow contributed 52,000 metric tons (57,000 tons) of dissolved solids per year to the White River. The well was subsequently plugged, after which the hydrostatic pressure built up, causing other non-flowing wells in the area to flow, and creating saline seeps in the vicinity of these wells.

A study of potential ground-water contamination from geophysical boreholes made by the Montana Bureau of Mines and Geology indicated that ten seismic companies drilled nearly 301,000 seismic holes in Montana in the 1950-1970 period. 66) It was found that standard practice for plugging seismic holes is to place a cement, plastic, or natural rock plug one to 3 m (3 to 10 ft) below the ground surface, whereupon the hole is filled to the surface with drill cuttings. For flowing holes, most companies use an inflatable plug, then backfill with cement or drill cuttings. The investigators found that seismic holes tend to effectively plug themselves. Field tests carried out during exploration activities showed that practically all seismic holes sealed themselves within a few days after being shot. Although interflow between aquifers occurred through seismic holes in some situations, it was believed that seismic programs have had no noticeable effect on Montana's ground water.

BRINE INJECTION

Salt water is commonly produced together with oil and gas, and this oil field water can be considered a form of industrial waste.

In the production of oil, oil field brine is injected under pressure back into the oil reservoir to provide the necessary hydrodynamic drive in secondary recovery operations.

In many cases this is a safe and useful way to dispose of brine.

Oil-producing reservoirs are situated within formations containing saline ground water, so that injection of brine into them is not of great concern. The potential danger lies in failure of injection wells, which would cause brine wastes to flow into fresh-water zones. Once injected, the pressurized saline water is difficult to control. It may be diverted to paths of least resistance, known or unknown, natural or artificial. These escape routes multiply with proximity to the land surface and include such natural geologic phenomena as fractures and faults, variations in overburden pressure resulting from topographic relief, and secondary solution systems. They also include man-made outlets created by earlier exploration and production activities -- old bore holes, shot holes, oil and gas wells and abandoned producing wells penetrating the reservoir. 67)

The chemical characteristics of brine are also cause for concern. Oil field brines may be several times more saline than sea water (see Table 32) and highly corrosive to metals. Steel casings may easily corrode and break, allowing the injected fluid to disperse in the rock zones. Only small quantities of brine are needed to cause severe degradation of fresh-water aquifers.

Case Histories

There is practically no documentation regarding ground-water contamination caused by injection of fluids in spite of the large quantities of waste water injected in thousands of wells. In Wyoming, there are 2,264 injection wells and in Montana, 782. 69,70) As of 1972, in Colorado, a cumulative total of 160 billion cu m (one trillion barrels) of fluid had been injected into various formations. 71) In 1972, 22 million cu m (138 million barrels) of fluid were injected in Colorado oil fields while only 5 million cu m (32 million barrels) of oil were produced. Thus, the amount of fluid returned to the formation was more than four times the amount of oil withdrawn. Injection pressures ranged up to 20,000 newtons/sq m (3,000 psi).

Disposal of oil field waste liquid by oil companies must be approved by state authorities (e.g., the Oil and Gas Conservation Commission in Colorado). In one case, in an oil field in Logan County, Colorado, an oil company was allowed to dispose of oil field liquids by reinjecting the waste in the annulus between the string of production casing and the Pierre Shale and Niobrara Formation. 71)

Table 32. COMPARISON OF DISSOLVED SOLIDS IN SEA WATER AND OIL FIELD BRINE.[68)]

Element	Sea water, mg/l	Oil field brine, mg/l		
Sodium	10,600	12,000	to	150,000
Potassium	380	30	to	4,000
Lithium	0.2	1	to	50
Rubidium	0.12	0.1	to	7
Cesium	0.0005	0.01	to	3
Calcium	400	1,000	to	120,000
Magnesium	1,300	500	to	25,000
Strontium	8	5	to	5,000
Barium	0.03	0	to	1,000
Chloride	19,000	20,000	to	250,000
Bromine	65	50	to	5,000
Iodine	0.05	1	to	300

DISPOSAL WELLS

In addition to brine and oil field waste injection wells used by the oil industry, there are several other types of disposal wells in the Northwest. A few deep wells have been drilled to dispose of industrial waste, and an estimated 8,000 wells dispose of domestic and agricultural waste fluids in the states of Oregon and Idaho. The impact of these disposal practices on ground-water quality depends on various factors, including quantity, type, and concentration of waste fluid injected, the rate of injection, permeability of the aquifer, composition of the native ground water, and dilution within the aquifer.

A potential threat to ground-water quality is posed by the thousands of disposal wells in Idaho and Oregon, most of which discharge waste waters to the unsaturated zones of basalt aquifers. A variety of contaminated fluids is discharged into these wells, including agricultural runoff, domestic and municipal sewage, and storm runoff from urban areas. The federal government and a few industries use deep wells to dispose of radioactive and chemical wastes.

Case Histories

A well-documented case of deep well disposal occurred at the Rocky Mountain Arsenal in Denver. 72,73) This arsenal manufactured chemical warfare products and discharged waste fluids to leaky disposal ponds, causing contamination of ground water and crops. As an alternate disposal method, an injection well was drilled to a depth of 3,617 m (12,045 ft), and starting in 1962, waste water was injected into fractured Precambrian rocks. Injection rates ranged between 12.6 and 19 l/s (200 and 300 gpm). Soon after the start of injection, tremors and earthquakes took place in the Denver area. A direct correlation between earthquake and injection frequency was established, injection was stopped, and tests were made to determine the feasibility of removing the fluid. 74,75)

There is an active deep disposal well operation located near Cheyenne, Wyoming. Nitrate waste is injected into a sandstone bed of the Pierce Formation at a depth of 1,500 m (5,000 ft). Although no ground-water problems have been reported, local health agencies are concerned about the potential impact on ground-water quality from this facility. 76)

Disposal wells are also in use at the National Reactor Testing Station (NRTS) in Idaho. One well at the Test Reactor Area (TRA) is 395 m (1,300 ft) deep and has been used since

1969 for disposal of about 570,000 cu m (150 million gallons) per year of nonradioactive waste water. 77) The injected fluid contains about 1,200 mg/l of dissolved solids, which is approximately five times as much as that of the natural ground water in the area. In addition, the water discharged before 1972 also contained one to 2 mg/l of hexavalent chromium. Estimates are that the bulk of the discharge is to the Snake Plain aquifer at depths of 150 and 210 m (500 and 700 ft).

Another disposal well at the Idaho Chemical Processing Plant on the same NRTS site also discharges fluids directly into the Snake Plain aquifer. This well is 180 m (600 ft) deep. Potential contaminants injected are tritium, sodium chloride, and sulfuric acid. A total of 23,000 curies of radioactivity, 7,100 metric tons (7,800 tons) of salt, and 730 metric tons (800 tons) of sulfuric acid have been discharged to this well since 1952 (see Table 33). The effects of radionuclides on ground-water quality are discussed in the section on radioactive waste disposal.

There are an estimated 3,000 disposal wells in Oregon, the majority of which are used for domestic waste disposal. In the Portland area, some wells are used to recharge water utilized for air conditioning. In 1968, a comprehensive investigation was made of disposal wells in the lava terrane of central Oregon by Sceva. 77) The disposal wells in this area are tied into septic tank systems and are generally drilled to the underlying lava, to a depth where cracks and crevices can receive and disperse the effluents. A schematic diagram of a typical sewage disposal well in lava terrane is shown on Figure 46. No major ground-water quality deterioration was noted during the survey, but little or no filtration is provided by the lava rock and the threat of contamination exists. Deep, uncased water wells were found to be particularly hazardous. Figure 47 illustrates the mechanism of potential contamination of an uncased water well by septic effluent discharged into a disposal well. Recent laws passed in Oregon require permits for waste disposal wells as of January 1, 1975, and prohibit construction or use of such wells after January 1, 1980. 79)

In Idaho there are some 5,000 disposal or drain wells in the Snake River Plain. Approximately 3,000 drain wells are concentrated in Lincoln, Jerome, and Gooding Counties (see Table 34). 79) Results of an investigation of the effects of disposal wells on ground-water quality by the Idaho Bureau of Mines indicate that drain wells are used where geologic conditions at or near the ground surface render conventional disposal systems impractical. In many areas soil

Table 33. AVERAGE COMPOSITION OF LIQUID WASTE EFFLUENT DISCHARGED AT THE IDAHO CHEMICAL PROCESSING PLANT DISPOSAL WELL. 78)

Waste Product	Half-life	Approximate Average Annual Discharge 1962-1972	Average Concentration in Effluent 1962-1972	Approximate Total Discharge Since 1952
Tritium (H^3)	12.3 years	505 Ci	430 pCi/ml	22,000 Ci
Strontium-90 (Sr^{90})	28.9 years	4 Ci	3 pCi/ml	18 Ci
Cesium-137 (Cs^{137})	30 years	4 Ci	3 pCi/ml	18 Ci
Zirconium-niobium-95 (Zr^{95}-Nb^{95})	65 days	2 Ci	1.5 pCi/ml	62 Ci
Cerium-144 (Ce^{144})	284 days	1 Ci	1.5 pCi/ml	96 Ci
Ruthenium-rubidium-106 (Rh^{106}-Ru^{106})	368 days	1 Ci	1 pCi/ml	23 Ci
Total Radioactivity	-	520 Ci	440 pCi/ml	23,000 Ci
Sodium chloride			160 mg/l Na	
(NaCl)		390 tons	245 mg/l Cl	7,800 tons
Sulfuric acid				
(H_2SO_4)		40 tons	45 mg/l SO_4	800 tons
Sodium hydroxide				
(NaOH)		14 tons		280 tons
Dissolved solids			600 mg/l	
Temperature			70°F (21°C)	

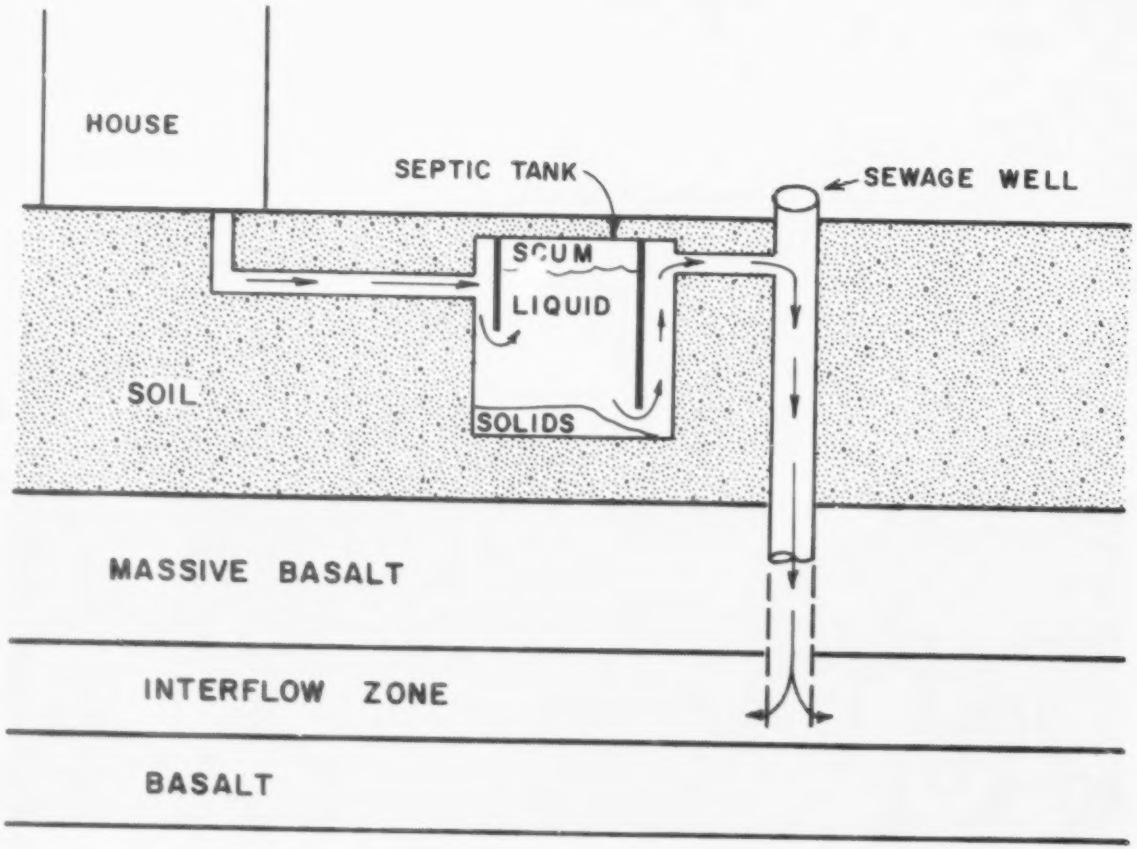

HOUSE
SEPTIC TANK
SEWAGE WELL
SCUM
LIQUID
SOIL
SOLIDS
MASSIVE BASALT
INTERFLOW ZONE
BASALT

Figure 46. Schematic diagram of a typical sewage disposal well in lava terrane. 79)

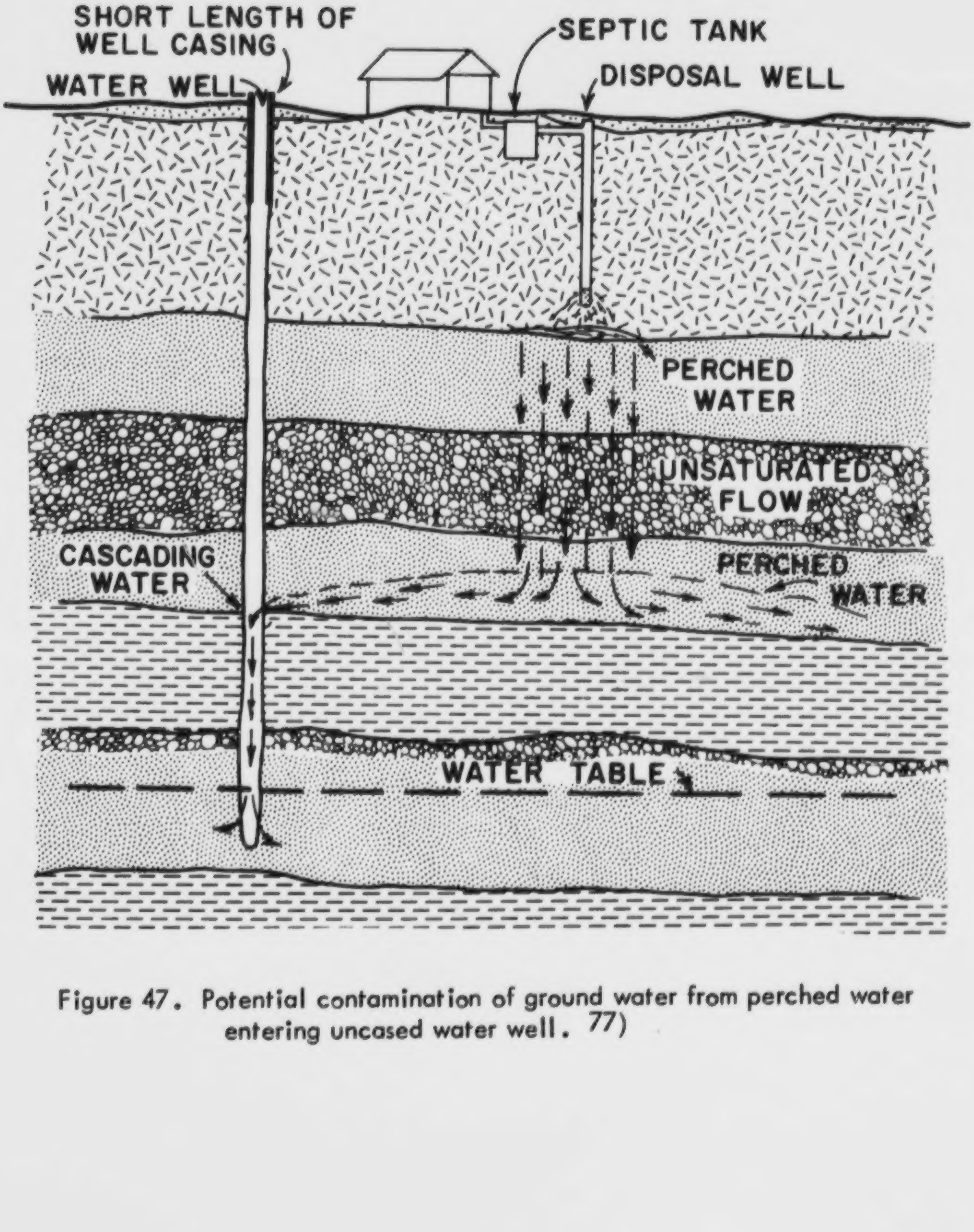

SHORT LENGTH OF
WELL CASING
SEPTIC TANK
WATER WELL
DISPOSAL WELL
PERCHED
WATER
UNSATURATED
FLOW
CASCADING
WATER
PERCHED
WATER
WATER TABLE

Figure 47. Potential contamination of ground water from perched water entering uncased water well. 77)

Table 34. NUMBER OF DRAIN WELLS IN THE SNAKE RIVER PLAIN (By County)
79)

County	Approximate Number of Drain Wells
Bannock	Less than 10
Bingham	200
Blaine	Less than 10
Bonneville	1000
Butte	Less than 10
Camas	Less than 10
Cassia	Less than 10
Fremont	50
Gooding	1000
Jefferson	50
Jerome	1000
Lincoln	1000
Madison	Less than 10
Minidoka	100
Power	50*
Twin Falls	20
Estimated Total	5000

*Mostly natural sinks in the lava.

cover is thin and often impermeable, and septic tanks cannot function properly. In addition, it was found that many people believe that wastes will be rendered harmless by natural purification in the subsurface.

The numerous openings, fractures, channels, and lava tubes in the basalt aquifer make it possible to discharge large volumes of waste fluid without any apparent effects. For this reason, disposal wells are seldom cased beyond the first basalt layer and almost never grouted. Most are used to dispose of septic effluent. The second most common use is for removing excess irrigation water in areas where topographic features limit or prevent natural drainage. The third is to dispose of street runoff where storm sewers are absent. Such wells are normally drilled on street corners and near catch basins. A few drain wells are presently employed to remove industrial wastes. In the past, drain wells were used to dispose of slaughter and tanning wastes and wastes produced by fertilizer plants.

Pollution of a public water-supply well by a drain well was detected in 1960 in the city of Idaho Falls. Fluorescein dye was injected to trace the contaminant and appeared in the supply well located 57 m (190 ft) from the drain well in 90 minutes. 79) Bacterial contamination of domestic wells by waste water discharged into irrigation drain wells was documented south of Idaho Falls.

In spite of the large volume of waste being discharged to the Snake Plain aquifer, reported incidents of serious contamination are few. This is attributed to the excellent permeability of the aquifer and the large underflow of ground water which dilutes these fluid wastes.

The Idaho Department of Water Resources is currently investigating the effects of disposal-well use on ground-water quality and updating estimates of the number and types of active disposal wells. The State has imposed a strict control program over this practice and relatively few permits are being approved. 80)

SURFACE IMPOUNDMENTS

Surface impoundments include lagoons, tailing ponds, basins, and pits used for storing, processing, or treating waste fluids. Some of these impoundments are designed to hold and evaporate liquid waste; others are designed to infiltrate liquid into the soil system. The inflow and outflow of fluids in surface impoundments are rarely metered, and consequently large volumes of a potential contaminant can be leaked to the subsurface before discovery. Some are lined with layers of cement, asphalt, plastic, or clay.

In mining areas, tailings or waste material are often used to dam a valley to form a reservoir for waste fluids. These ponds are commonly of two types: those receiving effluent from the concentrating process only, and those receiving the combined effluent from the concentrating process, mine drainage, and smelting or refining processes. The prime reason for such impoundments or tailing ponds is to aid in the removal of suspended solids prior to discharge into streams, and properly managed, such systems prevent or reduce surface-water pollution. However, in many cases, impoundments have been constructed with little thought given to the potential impact on the ground-water system.

Many unlined ponds are constructed in areas underlain by highly permeable alluvial material or highly fractured bedrock, and are poorly maintained. Leaching of heavy metals to the subsurface and to the water table frequently takes place. Lining of ponds with clay or plastic offers only limited protection against leakage and infiltration because they are susceptible to punctures, tears, and deterioration. Clay materials are not impermeable, and large quantities of polluted waste water can leak through the bottom of an impoundment to damage ground-water supplies. For example, a lagoon 8 ha (20 acres) in size and 3 m (10 ft) deep, lined with a 60 cm (2 ft) thick clay blanket with a typical permeability of 0.004 cm/d (0.001 gpd/sq ft) can leak about 57,000 cu m (1.5 million gallons) of fluid per year into the ground-water system. If the rate of ground-water movement is 15 cm (0.5 ft) per day and the nearest water well is 300 m (1,000 ft), it would take more than five years before the plume of contaminated water would arrive at the well. In the meantime, 284,000 cu m (7.5 million gallons) of the waste water would have leaked into the aquifer.

Unlined basins are used to dispose of treated sewage effluent at some treatment plants and for storage of liquid raw materials and waste effluent by industry. The pollutants from sewage lagoons that contaminate ground water are essentially the same as those from septic systems.

Case Histories

In Colorado, disposal of liquid chemical waste into unlined holding ponds at the Rocky Mountain Arsenal near Denver caused pollution of shallow ground water in an area of 30 sq km (12 sq mi) of the South Platte River valley. 81,82,83) The problem was discovered through damage to crops that were irrigated with water from shallow wells. The contaminated water moved northwestward in the direction of flow of the ground water toward the South Platte River (Figure 48). Contaminants known to be present in the shallow aquifer included chloride, fluoride, arsenic, chlorate, the herbicide 2-4D, and the pesticides aldrin and dieldrin. 22) A total of 119 observation wells was installed and a systematic study of water quality was undertaken to map the extent of contamination by measuring chloride concentrations in shallow wells. These concentrations reached a maximum of 4,600 mg/l in several areas. The approximate rate of ground-water movement was 4 m (13 ft) per day or about 1,500 m (4,800 ft) per year. Damage claims totaling $74,000 were paid by the government to five farmers that had suffered crop damage. 83)

Upon discovery of contamination of the shallow aquifer, waste discharge to leaky ponds was discontinued. The volume of industrial waste was reduced and a new reservoir lined with an asphalt membrane was put in operation. In 1961, a deep disposal well was installed at a cost of $1,419,000, and waste was discharged to the Precambrian zone. The use of the well was discontinued and the well was capped in February 1966 after correlation of disposals with recent earthquakes in the area was proven. Since that time, wastes have been discharged to a lined disposal pond.

The water-quality data collected during the 30-year monitoring history at the Rocky Mountain Arsenal was utilized in a model designed to predict mass transport in the shallow aquifer. 84) The results indicated that the geologic framework of the area markedly restricted the transport and dispersion of dissolved chemicals. Dilution from irrigation returns and seepage from unlined canals proved to be an important factor in reducing the level of chemical concentrations in the contaminated ground water.

At the town of Pierce in Colorado, increased mineralization of ground water caused the abandonment of two municipal wells. 85) An investigation by the Colorado Division of Water Resources indicated that oil field brines had caused the problem. The town is located in the center of an oil field where oil has been produced since the early fifties. Saline water associated with oil production was stored in unlined pits until 1969. Records show that 75,000 cu m (470,000 barrels) of fluid were unaccounted for in the reinjection process. It is unclear what the principal source of pollution has been over the years, but leaky surface impoundments have probably played a major role. A zone of polluted ground water about 20 to 30 m (70 to 100 ft) wide was found to extend through the center of town to the vicinity of the

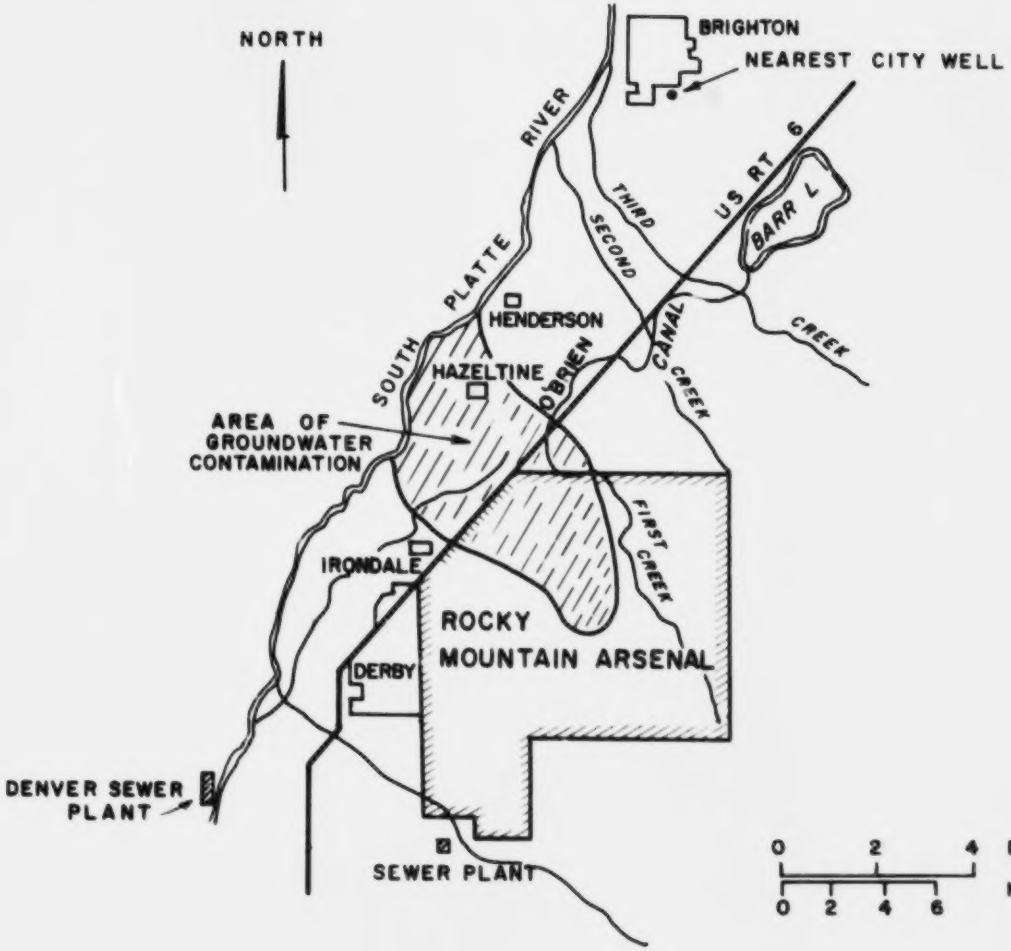

NORTH
BRIGHTON
NEAREST CITY WELL
US RT 6
BARR L
RIVER
PLATTE
SOUTH
THIRD
SECOND
CREEK
CANAL
CREEK
O'BRIEN
HENDERSON
HAZELTINE
AREA OF GROUNDWATER CONTAMINATION
FIRST
CREEK
IRONDALE
ROCKY MOUNTAIN ARSENAL
DERBY
DENVER SEWER PLANT
SEWER PLANT
0
2
4
MILES
0
2
4
6
KM

Figure 48. Area of ground-water contamination at Rocky Mountain Arsenal, Denver, Colorado. 82)

municipal wells. Chloride concentrations in the town wells increased from about 50 mg/l to 700 mg/l over a period of years, and recommendations were made to redrill the water wells elsewhere.

In Montana, numerous lagoons and tailing ponds are in use by a copper company in the Anaconda area. Waste water is put into ponds that together cover an extensive area, and as a form of treatment, lime is added. Leakage from the ponds has caused an increase in dissolved calcium sulfate in the ground water. 27)

A paper mill in the Missoula Valley has experienced problems from disposal of kraft effluent in settling ponds. Plant production wells tapping the alluvial deposits close to these ponds showed increased amounts of dissolved minerals, and some were abandoned. New wells were drilled away from the ponds and close to the Clark Fork River. 86) Heavy pumpage from the plant wells keeps the pollutant from spreading to adjacent areas.

Waste fluids stored in lagoons at a sugar refinery in eastern Montana have infiltrated the soil, entered the underlying ground water, and polluted nearby wells. Beet processing water contaminating ground water is high in BOD and has a distinct odor. 27)

Complaints of water well owners in the Great Falls, Montana, area led to an investigation of waste lagoons at a slaughter house. It was found that lagoon wastes were seeping into sandstone channels which were in hydraulic connection with fine-grained, saturated sand deposits. These sands are widely used by domestic water wells. 27)

In the Coeur d'Alene mining district of Idaho, a study of ground-water contamination in one valley indicated that water in settling ponds was not the source of high heavy metal concentrations in ground water. 87,88) However, the ponds acted as a recharge area for the sand and gravel aquifer, and thus caused the water table to rise. The upper portion of the aquifer contains old mine tailings with up to 6.0 percent lead and up to 4.4 percent zinc. As the ground water rose and saturated these mine tailings, it carried into solution increased concentrations of the heavy metals. Seeps and springs emerging on the valley floor downgradient from the settling ponds had lead concentrations ranging from 0.6 to 1.6 mg/l, cadmium concentrations ranging from 0.20 to 0.40 mg/l, and zinc concentrations ranging from 6 to 37 mg/l. A diagrammatic cross section of this situation is shown on Figure 49. Research is being carried out at the University

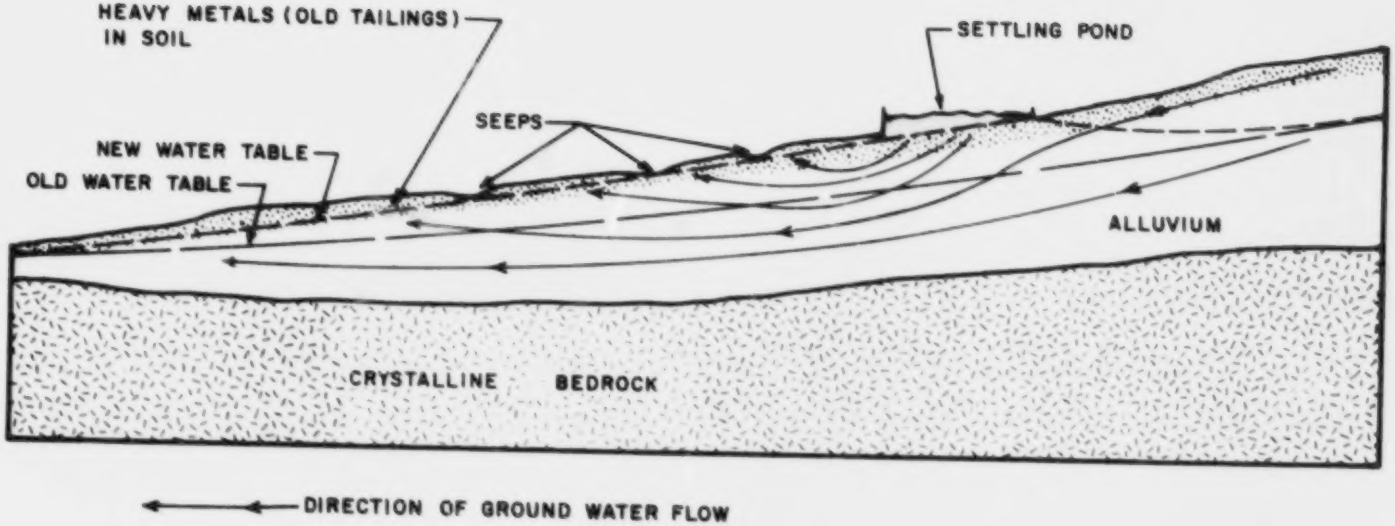

HEAVY METALS (OLD TAILINGS) IN SOIL
SETTLING POND
SEEPS
NEW WATER TABLE
OLD WATER TABLE
ALLUVIUM
CRYSTALLINE BEDROCK
DIRECTION OF GROUND WATER FLOW

Figure 49. Diagrammatic cross-section of ground-water pollution caused by settling ponds and mine tailings in northern Idaho.[88]

of Idaho in renovation of waste water and the prevention of leakage from tailing ponds in the Coeur d'Alene mining district. 80,89,90,91)

Prior to November 1968, the mines in the South Fork area of the Coeur d'Alene River discharged their tailings and liquid waste directly into the South Fork causing severe surface-water pollution. Since that time settling ponds have been built. These ponds have a beneficial effect on surface-water quality by reducing suspended solids, but their effect on concentration of soluble metals and the overall impact on ground-water quality is not yet clear. 88)

Ground-water contamination from sewage lagoons has occurred at Tieton near Yakima, Washington. Domestic, commercial, and industrial wastes of the community were discharged to a lagoon located in a narrow valley underlain by permeable sands and gravels. Average daily waste flow was 490 cu m (130,000 gallons), of which 190 cu m (50,000 gallons) were domestic and the balance industrial waste waters. Within a few months after discharge to the pond began, a well located 75 m (250 ft) south of the lagoon became contaminated. Investigation showed that coliform bacteria had traveled from the lagoon to the well. Anionic synthetic detergent had also entered the aquifer. A tracer study using chloride showed that sewage infiltrating through the bottom of the lagoon formed a shallow, elongated mound of fluid resting on top of the water table. Flow velocities of ground water below the lagoon were in excess of 90 m (300 ft) per day. About 300 m (1,000 ft) down the valley the velocity decreased to 60 m (200 ft) per day. Water from the lagoon reached rural water wells as far as 450 to 600 m (1,500 to 2,000 ft) down the valley in six days. 92)

Little consideration was given to potential contamination of ground water when the lagoon was constructed. Infiltration rates at the lagoon ranged from 7.5 to 38 cm (3 to 15 in) per day indicating highly permeable soil conditions with little or no filtration or treatment capability. 92)

On the Kitsap Peninsula near Bangor in the same state, shallow ground water has become contaminated as a result of dumping of TNT waste at a U. S. Navy installation. This waste, resulting from steam cleaning of deactivated ammunition, was discharged into a catch basin during World War II, and contamination of ground water was only discovered in 1970. Monitoring wells have been installed and the problem is under investigation by the U. S. Geological Survey and the Washington Department of Ecology. 93)

MINING

The rich mineral deposits in the Northwest have been explored and developed for over a hundred years. Hundreds of mines have been developed to obtain precious metals, ores, and coal. The mining industry is an important segment of the economy and is expected to undergo rapid growth in connection with the federal government's drive for self-sufficiency in energy. In 1971, the value of minerals produced in the six states was over half a billion dollars (Table 35). Major minerals are copper, coal, uranium, zinc, silver, and lead. Also of economic importance is the production of sand, gravel, clay, and stone.

Contamination of ground water from mining activities stems from acid mine drainage and from leaching of mine tailings. Acid mine drainage results when water and oxygen come in contact with pyrite or other iron-sulfide bearing minerals to form sulfuric acid. This acid water is pumped or seeps from the mine or mineral deposit and is discharged at the land surface. As shown on Table 36, acid mine drainage and sediments entering streams and rivers in the Northwest affect fish and wildlife along more than 2,400 km (1,500 mi) of streams, 1,400 km (880 mi) of which are in Colorado. 95)

Drainage from coal mining activities is considered to be an important environmental problem. Principal pollutants found in coal mine drainage are acids, sulfates, iron, and trace elements. 68) Table 37 shows some of the trace elements found in coal beds of Montana and Wyoming. 96) Arsenic, fluorine, mercury, selenium, zinc, and lead are present in significant concentrations. However, data is not available as to whether these constituents are significant ground-water pollutants throughout the mining region.

There were 20 strip mines producing bituminous coal and lignite in the Northwest in 1965. 95) Of these, nine were in Wyoming, seven in Colorado, three in Montana, and one in Washington. These operations disturbed only a small area of land (2,200 ha or 5,400 acres) compared to the total land area disturbed by all types of strip and surface mining operations (61,400 ha or 151,500 acres). Most of the land was disturbed by sand and gravel and gold mining operations (Table 38). These conditions are expected to change drastically in the future when surface mining of coal on the Great Plains will begin. In a report on rehabilitation of coal lands issued by the National Academy of Sciences (NAS), it is estimated that 360 sq km (140 sq mi) would be disturbed by surface mining by 1990, and about 780 sq km (300 sq mi) by the end of the century. 97) Figure 50 shows the areas of

Table 35. MAJOR MINERAL PRODUCTION IN THE NORTHWEST EXCLUSIVE OF PETROLEUM AND RELATED PRODUCTS. 94)

State	Mineral	Dollar Value 1971 Thousands
Colorado		
	Coal	33,813
	Sand & Gravel	30,155
	Zinc	19,700
	Uranium	15,725
	Stone	7,933
Idaho		
	Silver	29,590
	Lead	18,384
	Zinc	14,515
	Sand & Gravel	11,437
	Stone	6,118
Montana		
	Copper	92,125
	Sand & Gravel	25,207
	Coal	12,817
	Silver	4,248
	Lime	2,416
Oregon		
	Sand & Gravel	28,707
	Stone	26,708
	Lime	1,989
	Pumice	1,239
	Gem Stones	755
Washington		
	Portland Cement	26,848
	Sand & Gravel	26,069
	Stone	23,764
	Lime	1,989
	Pumice & Volcanic Cinder	1,239
	Gem Stones	755
Wyoming		
	Uranium	43,311
	Coal	27,335
	Clays	17,378
	Sand & Gravel	8,750
	Stone	4,789

Table 36. FISH AND WILDLIFE HABITAT ADVERSELY AFFECTED BY STRIP AND SURFACE MINING IN THE NORTHWEST AS OF JANUARY 1, 1967. 95)

	Streams				Reservoirs and impoundments			Wildlife habitat	
	Length		Surface		Number	Surface			
State	km	mi	ha	acre		ha	acre	ha	acre
Colorado	1,408	880	782	1,930	13	243	600	8,714	21,515
Idaho	214	134	265	654	-	-	-	6,666	16,460
Montana	218	136	95	234	-	-	-	4,386	10,830
Oregon	496	310	251	620	-	-	-	5,535	13,666
Washington	102	64	259	640	-	-	-	-	-
Wyoming	16	10	81	200	-	-	-	-	NA
Total:	2,454	1,534	1,733	4,278	13	243	600	25,301	62,471

NA - Not available

Table 37. CONCENTRATIONS OF SELECTED TRACE ELEMENTS IN SOME MONTANA AND WYOMING COAL BEDS. [96]

(In parts per million, rounded)

	Coal, Big Sky Mine			Other coal beds	
	Rosebud [a]	McKay	Tipple sample	Range	Average
Arsenic	1	1	2	1 - 5	3
Fluorine	40	70	60	10 - 60	30
Mercury	0.06	0.05	0.07	0.02 - 0.2	0.07
Selenium	0.5	0.4	0.5	0.1 - 1.5	0.5
Zinc [b]	2	3	5	2 - 54	12
Lead [b]	5	5	8	4 - 30	11

a) Weighted average.

b) Recalculated from analyses on coal ash.

Table 38. LAND DISTURBED BY STRIP AND SURFACE MINING IN THE NORTHWEST AS OF JANUARY 1, 1965 (in acres). 95)

State	Clay	Coal (bituminous, lignite and anthracite)	Stone	Sand and Gravel	Gold	Phosphate Rock	Iron Ore	All Other	Total
Colorado	2,000	2,800	6,200	15,500	17,100	-	25	11,400	55,025
Idaho	500	-	700	11,200	21,200	3,100	35	4,200	40,935
Montana	-	1,500	10	13,500	5,600	100	10	6,200	26,920
Oregon	100	-	300	1,300	6,300	-	10	1,400	9,410
Washington	500	100	1,300	5,700	400	-	20	800	8,820
Wyoming	3,500	1,000	300	200	-	800	300	4,300	10,400
Total Acres:	6,600	5,400	8,810	47,400	50,600	4,000	400	28,300	151,510
Hectares:	2,700	2,200	3,600	19,200	20,500	1,600	160	11,500	61,400

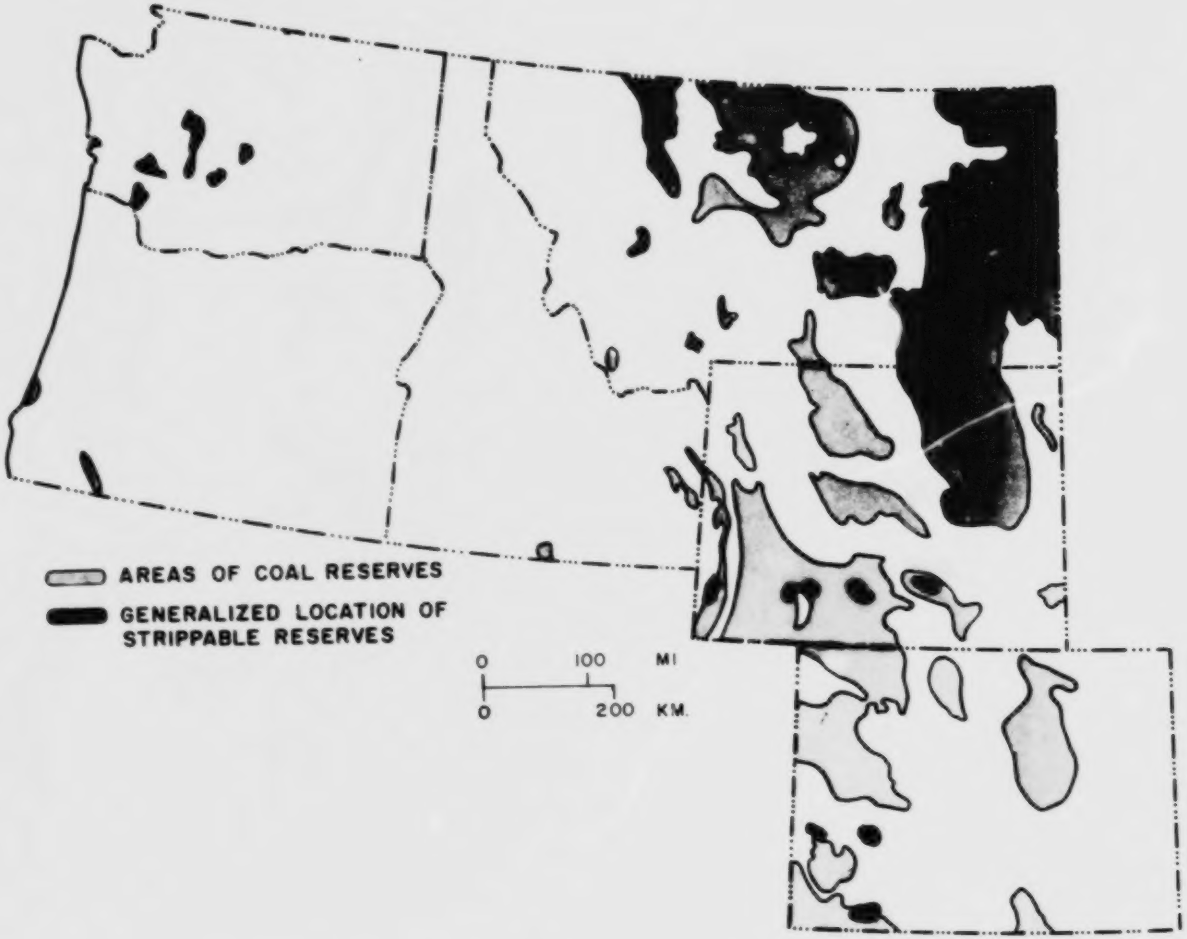

AREAS OF COAL RESERVES
GENERALIZED LOCATION OF STRIPPABLE RESERVES
0
100
MI
0
200
KM.

Figure 50. Areas of coal reserves and strippable reserves. 97)

coal reserves and the extent of the major strippable coal areas in the Northwest, and Table 39 lists the strippable coal resources and recoverable coal. Together, Wyoming and Montana contain 96 percent of the recoverable strippable coal. Most of the strip mining and disturbing of land will take place in these two states.

Underground gasification of coal as an alternative to mining is presently under study. Basically, this process involves hydraulic fracturing of the coal seam to increase permeability, after which the coal is ignited. Gasification is maintained by injecting air to support combustion through bore holes. Product gas is then piped to the surface and cleaned to produce a non-polluting fuel. Potential environmental problems created by this process are land subsidence and contamination of ground water.

A pilot operation, the Hanna Underground Coal Gasification Project, is currently underway in Wyoming to investigate the problems. A large part of this experiment is aimed toward obtaining baseline data of ground-water quality updip and downdip from the combustion zone. Chemical analyses show that the natural coal seam water is of marginal quality with dissolved solids concentrations ranging from 2,000 to 6,000 mg/l. Trace elements generally exist in low concentrations. Copper, nickel, chromium, manganese, zinc, cadmium and aluminum are present at less than 0.05 mg/l; boron is less than 0.2 mg/l; iron less than 0.15 mg/l; lead less than 0.1 mg/l; arsenic less than 0.006 mg/l; and mercury less than 0.002 mg/l. 98) The effects of coal gasification on ground water have not been studied to any large degree. In the USSR, an increase in ground-water temperatures of the surrounding region was noted, which could conceivably increase the soluble salt content of ground water. 99)

More than 9,000 abandoned and inactive underground mines in the Northwest were tabulated in one national survey (Table 40). About 7,500 of these are metal mines. 95) This figure appears to be conservative as the Colorado Bureau of Mines estimates the number of abandoned mines in Colorado alone at 30,000. 100) Drainage from these inactive metal mines may contain substantial concentrations of dissolved solids and metallic minerals in addition to being acid.

The mining of oil shale may eventually be undertaken on a large scale in Colorado and Wyoming. Basins of known oil shale deposits are shown on Figure 51. The Department of the Interior has leased two 2,000 ha (5,000 acre) tracts in Colorado to oil companies on the condition that mining be done conventionally, either by surface or underground tech-

Table 39. STRIPPABLE RESOURCES AND RESERVES OF COAL IN THE NORTHWEST AS OF JANUARY 1, 1968. [97]

(Thousand Short Tons)

	Average Thickness (feet)	(meters)	Remaining strippable resource (0-130 feet overburden)[a]	Recoverable strippable resource	Strippable reserves
COLORADO					
Bituminous	12	3.6	870,000	696,000	500,000
Subbituminous	-	-	-	-	-
Lignite	-	-	-	-	-
Total:			870,000	696,000	500,000
MONTANA					
Bituminous	-	-	-	-	-
Subbituminous	28	8.4	7,813,000	6,250,000	3,400,000
Lignite	19	5.7	7,058,000	5,646,000	3,497,000
Total:			14,871,000	11,896,000	6,897,000
WASHINGTON					
Bituminous	-	-	-	-	-
Subbituminous	22	6.6	500,000	400,000	135,000
Lignite	-	-	-	-	-
Total:			500,000	400,000	135,000
WYOMING					
Bituminous	-	-	-	-	-
Subbituminous	67	20.1	22,028,000	17,622,000	13,971,000
Lignite	-	-	-	-	-
Total:			22,028,000	17,622,000	13,971,000

a) 0-40 meters overburden

Table 40. ABANDONED AND INACTIVE UNDERGROUND MINES IN THE NORTHWEST AS OF 1966.[95)]

State	Coal	Metal	Non-metal
Colorado	565	1,699	7
Idaho	11	1,749	208
Montana	334	1,691	146
Oregon	61	1,140	3
Washington	247	907	52
Wyoming	26	295	-
Total:	1,244	7,481	416

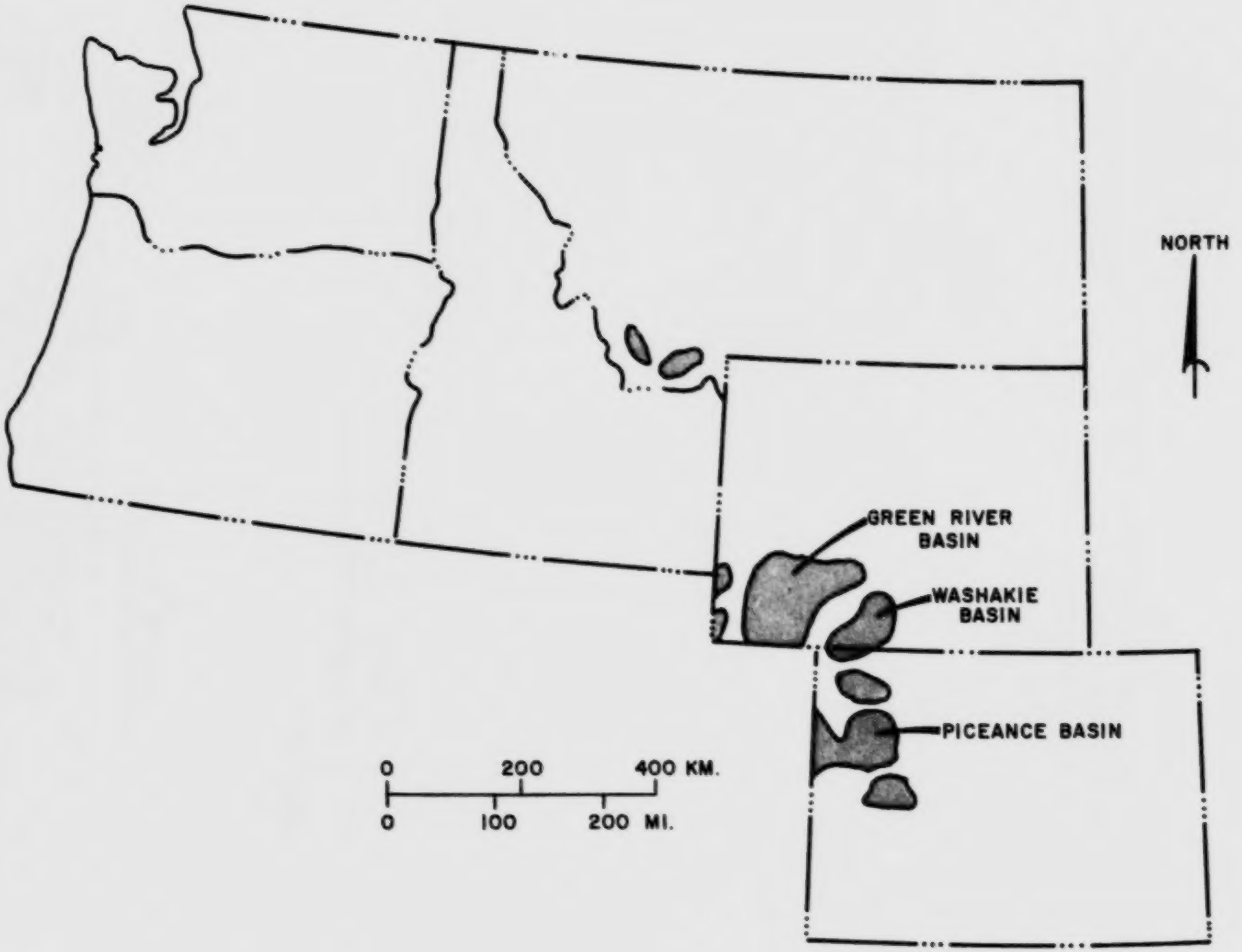

NORTH
GREEN RIVER BASIN
WASHAKIE BASIN
PICEANCE BASIN
0
200
400 KM.
0
100
200 MI.

Figure 51. Areas underlain by oil shale. 101, 102)

niques. Various mining methods and energy conversion processes are now under investigation by private industry and federal and state agencies. These include strip mining, vertical shaft, canyon wall mining and underground processing. At the present time, a plant on a 1,600 ha (4,000 acre) site in the Piceance Creek basin of Colorado is producing 4 to 5 cu m (25 to 30 barrels) of oil per day by in situ development. 103) Contamination of ground water may result from leaching of shale waste piles on the land surface or from in situ development. Estimates are that commercial oil shale operations planned for the Piceance Creek basin in Colorado could generate as much as 60 million tons of complex solid wastes annually by 1979. These wastes would contain not only inorganic trace elements and water-leachable salts, but also considerable amounts of residual organic matter containing aromatic hydrocarbons. 104)

Case Histories

An intensive study of the occurrence and production of acid drainage was carried out in a lead-zinc mine in northern Idaho. 105) At the time of the investigation, this mine discharged 170 l/s (2,700 gpm) of water containing heavy metals and with a pH of about 3.3. Flow measurement and water quality determinations were made at various levels in the mine and the zinc ore body. Differences in pH values were found between the older, upper levels and the newer, lower levels. Low pH water was found in areas of lead-zinc ore rich in pyrite. Vertical water movement in the mine was found to be important in the production of acid and the transportation of heavy metals. The quantity of acid drainage varied directly with the amount of surface runoff. The mine water and ore body water contained 0.03 to 2.8 mg/l cadmium, 15 to 1,095 mg/l zinc, 0.38 to 2.3 mg/l lead, and 3.1 to 838 mg/l iron. The pH ranged from 2.6 to 6.1.

In Montana, over 100 mines are contributing to the acid drainage problem. These include lead, copper, and silver mines in the Dry Fork-Belt Creek area. Tailings from these mines also pollute the streams.

Seepage from coal mines in the Sand Coolee district of north-central Montana also causes serious water pollution. This acid drainage originates as precipitation onto the Kootenai Formation, a fractured sandstone. The water percolates downward to the coal mines and emerges as acid water. Both tailings and drainage problems have been investigated by the Montana Department of Health. 27) Coal acid problems are also present in the Belt Creek area of Montana, where coals high in pyrite, contribute drainage which is very acidic and high in heavy metals.

There is considerable concern about the impact on groundwater quality from future coal strip mining in eastern Montana and Wyoming. Although the coal in Montana is lower in sulfur content (as pyrite) than eastern coal beds, acid water could be produced. Water-bearing sandstones are associated with these coal beds, and excavation of coal may destroy and dewater aquifers. In Wyoming, the NAS study on the potential for rehabilitation of strip mined land indicated that future strip mining and dewatering near Gillette would impair several hundred domestic water wells. It was also acknowledged that no known method to patch the gaps in coal-seam aquifers once the coal is removed presently exists. 97)

Other problems of acid mine drainage are reported in the Butte area and in the Upper Blackfoot River basin of Montana. In the Butte area, seepage from the town's sewage system reacting with minerals present in the soils causes acid drainage to streams.

Drainage from abandoned gold mines is believed to be the source of high manganese occurring in individual water supplies in Snohomish County, Washington. 106) North of Boise, Idaho, cases of cattle poisoning were reportedly caused by arsenic leachates from abandoned mines. 107) A small town in Jefferson County, Montana, has had problems with groundwater pollution caused by acid drainage from abandoned or closed mines. 108)

Old mine tailings deposited during past years when less efficient metallurgical processes were available are a significant threat to the water quality of the Coeur d'Alene Basin in Idaho. Although the hydrology of tailings piles under local climatic conditions in this river basin is not fully understood, it is known that ground water discharging through these tailings leaches the metal sulfides both biochemically and chemically. 90,91) Where the permeability of the aquifer is sufficiently high, discharging ground water contributes appreciable amounts of zinc to the surface-water drainage in the basin. This phenomenon is occurring in the sediments of Canyon Creek. In the Ninemile Creek area, old tailings have been deposited on sediments of lower permeability, and although the discharging ground water is noticeably high in metal content, the rate of discharge to streams is much lower. Consequently, the rate of addition of metal-rich ground water to streams in this area apparently is not sufficient to cause a significant surface-water quality problem.

A hydrogeologic study was made of a large tailings pile in northern Idaho covering 28 ha (70 acres) with a height of 7.5 m (25 ft). Tailing material was derived from a lead sulfide and zinc sulfide mine. A total of 112 piezometers was installed on and around the pile. Contours on top of the water table indicated a ground-water mound below the pile, and preliminary analysis of water-quality data showed that transfer of ions (calcium and potassium) was taking place from the pile to the surrounding ground-water system. 105) Leaching of heavy metals by water passing through mine tailings was also demonstrated in the Cataldo Mission Flats area of the Coeur d'Alene River valley. Mean concentrations of zinc and lead in ground water were 52 mg/l and 0.8 mg/l respectively. 89) Ground water for an industrial supply below Kellogg in the same valley contained 0.04 mg/l of cadmium and 25.0 mg/l of zinc. 109)

In western Colorado, leachate from uranium tailings has entered the rivers. One of the dumps is over 22 ha (54 acres) in size, and contains 2.3 million metric tons (2.5 million tons) of tailings. Recent stabilization of these piles appears to have helped to diminish infiltration and leaching. 110) Similar problems from uranium mining exist in the Shirley Basin in Wyoming where high Ra 226 has been found in ground water. 111) Weathering of piles of potassium dichromate at a plant site in Montana caused chromium to enter the underlying aquifer. Corrective action consisted of removal of the piles and chemical treatment of the soils. It is believed that the contaminated ground water is moving slowly toward the Yellowstone River. 27)

Leaching of sulfide-rich tailing piles near Ironton, Colorado, has caused surface-water pollution. The pH of Albany Gulch, a stream which flows through the waste-rock pile, was lowered by 3 pH units over a distance of about 50 m (50 yards). 112)

Several studies involving trace metals and ground-water quality are underway. The effects of molybdenum on the environment are currently being studied by a team of investigators in Colorado. 113) The Molybdenum Project Group at the University of Colorado has extensively sampled mining areas and surface-water drainage systems. Similarly, Colorado River basin waters have been tested for traces of vanadium associated with vanadium and uranium mining operations. In both cases, no data is available yet pertaining to ground-water quality. 114) The large trona mining operations in the Green River basin of Wyoming are currently being investigated as possible sources of ground-water contamination. Surface-water deterioration was responsible for initiating this investigation. 108)

A potentially troublesome ground-water situation was uncovered by a team of U. S. Department of Agriculture researchers involved in a program dealing with the reclamation of lignite strip mine spoil piles in eastern Montana and North Dakota. At the project site the team found coal seams interlaced with seams of shale in the Fort Union Formation containing large quantities of nitrogen locked into ammonia. Approximately 200 kg of exchangeable NH_4^+ nitrogen per hectare was found to be initially present in each meter of thickness of these sedimentary rocks. When exposed to air, water, and bacteria, this nitrogen would oxidize to become compounds potentially hazardous to ground water, but useful during the reclaiming of the mine spoil piles. Conclusions of the study were that strip mining or the irrigation of thousands of hectares of this shale would greatly enhance the potential for a dangerous NO_3 nitrogen buildup in surface and ground water and that well designed and well executed water control practices would be needed. 115)

LANDFILLS

Landfill refers to a land area used for dumping of solid waste from urban or rural communities and industry. Included in the waste materials are household and commercial refuse and waste products generated by factories. Other terms considered synonymous are refuse dumps and sanitary landfills. These wastes are dumped on top of the land surface, in excavations, in marshy or swampy areas, or in abandoned mines. Practically all dumps are not acceptable from an environmental point of view because of leachate production. Few are engineered or designed to prevent contamination of ground water and surface waters.

The volume of urban waste produced is in direct proportion to population, and most major landfills or dumps are thus in the Denver and foothills areas of Colorado, and in the Portland-Vancouver-Tacoma-Seattle region of Oregon and Washington. Industries are spread over the entire region, and their refuse dumps are generally remote from urban centers.

Production of leachate depends on the availability of water moving through the waste material. This water can be precipitation (rain or snow), moisture in the waste itself, or ground water or surface water entering the landfill site. Research studies have shown that 135 mm of water per m (1.62 in of water per ft) of depth of fill is necessary to produce leachate. 116) In the arid portion of the Northwest, landfills are generally not considered a problem as there is little or no leachate production. However, this is not the case in the moist climate west of the Cascade Range or in some areas of Idaho where annual precipitation is in excess of 1,000 mm (40 in) per year.

Case Histories

Urban waste dumped over a period of five years at a site north of the city of Moscow, Idaho, was found to have contaminated ground water. This site, covering 3 ha (7 acres), was located in a 10-ha (25-acre) basin on loess and alluvial material. These deposits were saturated most of the year due to a high water table. Electrical resistivity surveys and piezometers were used to map the extent of the contaminated ground-water body. 117)

In the Boise, Idaho area, leachate from a landfill located on a cliff has entered the ground water causing local well owners to complain. Hydraulic gradients were found to be very steep, causing the contaminated ground water to move rapidly. 24)

In Washington, no cases of contamination of water wells from landfills have been reported, but leachate generation has been detected at several dumping sites. In one county in the state, 7 of 15 landfill sites had "serious" leachate problems. 118) One large landfill operation situated on glacial drift was found to produce large amounts of leachate that emerged as springs along the banks of a stream. 119)

In Oregon, ground-water contamination has been detected from a landfill near Eugene located along a river. A total of 24 wells was installed to monitor the movement of the contaminated water. 30) Another landfill under study is located west of Portland. This landfill, now abandoned, is situated on volcanic terrane. Leachate from this site has affected some domestic wells, necessitating the replacement of water wells. 120)

Industrial dumps have created ground-water quality problems in some areas. Plywood plants in western Montana, which formerly burned wood wastes are no longer allowed to do so because of air pollution regulations. These wastes were then buried in gullies. Glue extracts in the wastes contained phenols which entered the ground water causing contamination of a water well. 27) Land disposal of wood wastes is also creating problems in Oregon. Leachates from sawdust, bark, and chips of bark contain tannic acid, which discolors the waters and lowers the pH. In the Willamette Valley, leachate from wet wood wastes dumped into an abandoned gravel pit near the city of Turner, has contaminated a number of domestic wells. 121) Some of these wastes were deposited below the water table, and there was a rapid dispersal of the contaminant. Within a period of five months, the contaminated plume moved 150 m (500 ft) and quadrupled in size (Figure 52). In Washington, sulfide liquors from wood and pulp mills discharged into pits have caused contamination of municipal water wells in the city of Shelton. 122)

Incompletely processed aluminum ore and mill tailings which had been treated with sulfuric acid and ammonium hydroxide were dumped into a sand and gravel pit at Keizer, Oregon, north of Salem. 123) The pollutant spread into highly permeable alluvial deposits used by many families for domestic water supply. The contamination was discovered in 1946 after the complaints of local residents. Analysis showed that the total dissolved solids concentrations in the water from one well exceeded 1,000 mg/l, ten times the normal concentration. To alleviate the problem and prevent further contamination, the waste was removed from the pit and two high capacity wells were pumped for several months to remove contaminated water. A water sampling program was established to monitor the extent and movement of the contaminated ground water (Figure 53). In 1947, the contaminated area covered 0.7 sq km (0.3 sq mi); in 1953 it had spread downgradient and included 2.0 sq km (0.75 sq mi). In 1964, the affected area was 2.6 sq km (one sq mi). The estimated rate of movement was 1.4 m (4.5 ft) per day or 500 m (1,700 ft) per year. Because of the slow rate of dispersion the contaminant will remain in the aquifer for many more years.

RADIOACTIVE WASTE

Radioactive waste disposal in the Northwest takes place primarily at the National Reactor Testing Station (NRTS) in Idaho and at the Hanford Reservation in Washington. Smaller amounts of solid wastes are disposed of at the Rocky Flats plant near Denver, Colorado. Most radioactive waste is in liquid form and is disposed of in ponds and cribs (trenches filled with gravel) or injected into wells. Solid waste is buried in isolated areas in special chambers or trenches. Disposal of radioactive fluids has been closely watched and monitored by the U. S. Geological Survey for the past 20 years. Numerous test and observation wells have been installed at disposal sites and ground-water quality is constantly monitored.

National Reactor Testing Station

Several facilities at the NRTS site in Idaho generate and

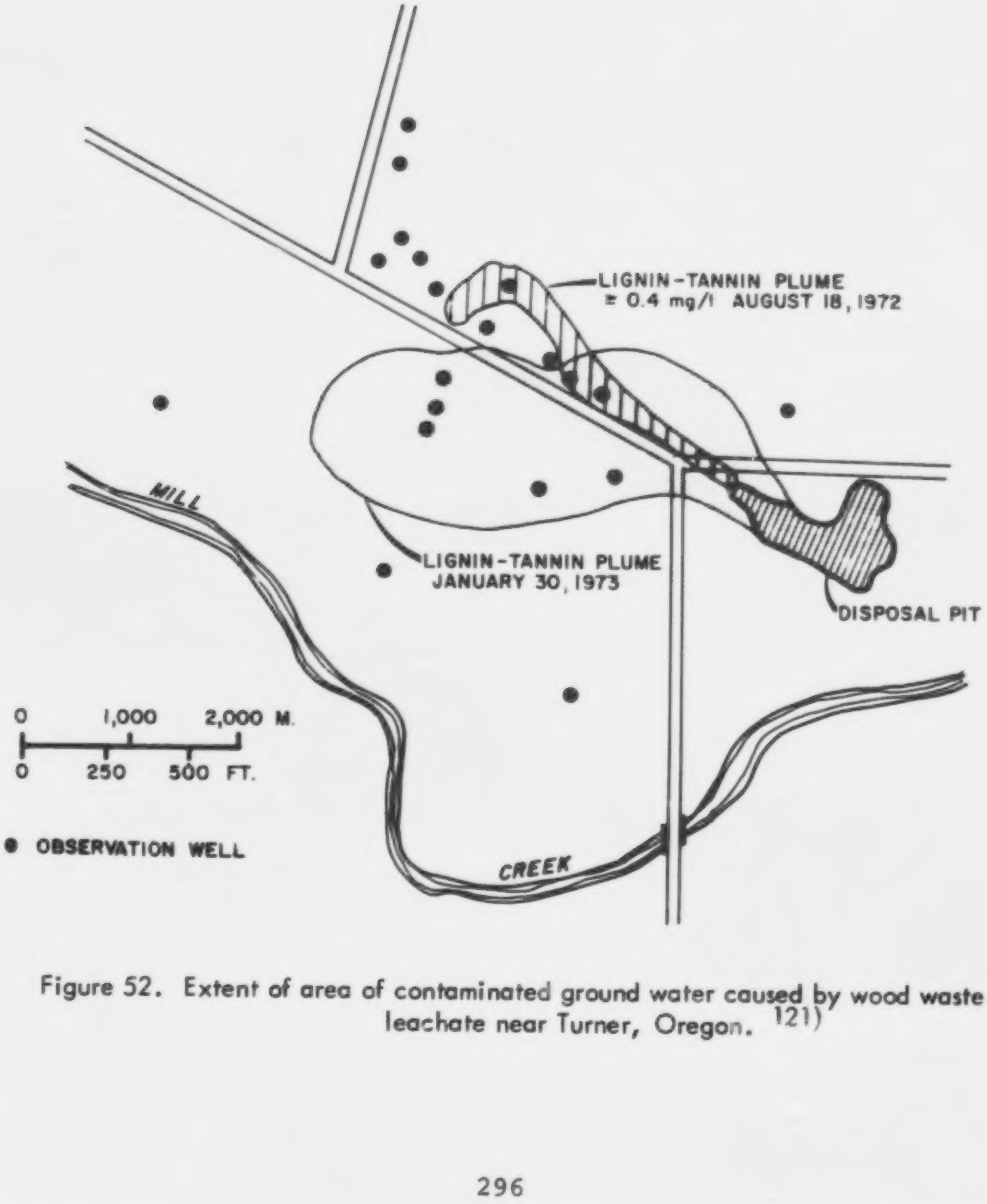
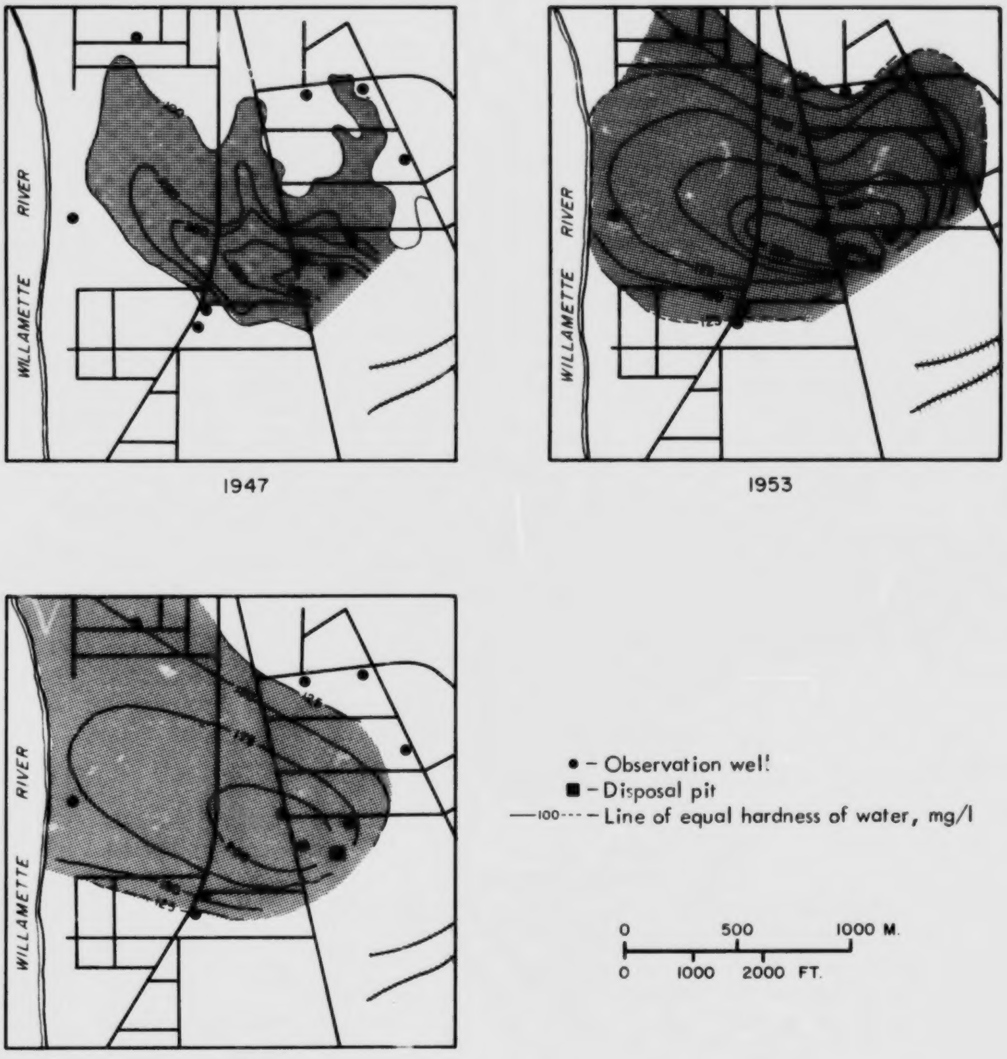

LIGNIN-TANNIN PLUME
≥ 0.4 mg/l AUGUST 18, 1972
LIGNIN-TANNIN PLUME
JANUARY 30, 1973
DISPOSAL PIT
MILL
CREEK
0
1,000
2,000 M.
0
250
500 FT.
● OBSERVATION WELL

Figure 52. Extent of area of contaminated ground water caused by wood waste leachate near Turner, Oregon. 121)



WILLAMETTE RIVER
WILLAMETTE RIVER
WILLAMETTE RIVER
100
125
125
125
125
● – Observation well
■ – Disposal pit
—100--- – Line of equal hardness of water, mg/l
0
500
1000 M.
0
1000
2000 FT.

1947

1953

1964

Figure 53. Extent of area of contaminated ground water at Keizer, Oregon. 123)

discharge low-level radioactive and dilute chemical liquid wastes to the subsurface by means of seepage ponds or wells. The two most significant waste-discharge facilities are the Test Reactor Area (TRA) and the Idaho Chemical Processing Plant (ICPP). Together these two facilities account for 75 percent of the total volume of liquid waste discharged to the ground here and include 80 percent of the total chemical wastes and over 90 percent of the total radioactive waste. 78) TRA wastes include several types, which discharged through four different disposal systems. Low-level radioactive wastes are discharged to three interconnected seepage ponds excavated in gravelly alluvium of the Lost River floodplain and allowed to percolate to the water table 137 m (450 ft) below land surface. Nonradioactive corrosive chemical wastes are discharged to a separate seepage pond. Nonradioactive cooling-tower blowdown wastes are directly injected into the aquifer through a deep well. Sanitary wastes go to another seepage pond. Discharge to the TRA radioactive-waste ponds has averaged 760,000 cu m (200 million gallons) per year.

About 70 percent of the low-level radioactive waste discharged to these ponds is short-lived with a half life of a few days or less. Table 41 lists the average discharge and concentration of longer-lived nuclides in liquid waste discharged to the ponds. Liquid chemical waste has been discharged to the TRA chemical waste seepage pond since 1962. About 170,000 cu m (44 million gallons) per year of chemical waste fluids is discharged to this pond. These wastes, originating from ion-exchange system regeneration, consist on the average of 910,000 kg (1,000 tons) per year of sulfuric acid, 450,000 kg (500 tons) per year of sodium hydroxide, and 45,000 kg (50 tons) of sodium chloride.

In addition to disposal ponds, two deep disposal wells are in use at the site (see previous discussion under Disposal Wells). At the TRA facility, nonradioactive waste water from cooling-tower blowdown is injected into a 395-m (1,296-ft) deep disposal well, and at the ICPP, located about 3 km (1.8 mi) southeast of the TRA site, low-level radioactive waste is discharged into a 180-m (590-ft) deep well. These wastes are discharged directly into the Snake River Plain aquifer.

Waste disposal in the TRA ponds has caused the formation of an extensive perched-water body beneath the ponds. 124) The water percolates downward through gravel, sand, and silt to a basalt layer 15 m (50 ft) below the surface. At first, the water formed shallow perched-water bodies in the alluvium above the basalt. Later the perched water seeped into the basalt and formed a second, larger perched-water body. Further downward movement is retarded by a layer of clay and

Table 41. LONGER-LIVED NUCLIDES BEING DISCHARGED AT THE TEST REACTOR AREA FACILITY ON THE NATIONAL REACTOR TESTING STATION SITE.[78)]

Waste nuclide	Half-life (years)	Approximate average discharge 1962 through 1972 (curies per year)	Average concentration 1962 through 1972 (picocuries per ml)	Approximate discharge since 1952 (curies)
Tritium (H^3)	12.3	500	615	8,300
Strontium-90 (Sr^{90})	28.9	5	6	70
Cesium-137 (Cs^{137})	30	5	6	110
Cobalt-60 (Co^{60})	5.2	20	25	400

silt within the basalt about 45 m (150 ft) below the surface and about 90 m (300 ft) above the regional water table. It is estimated that the average travel time of waste water from the ponds to the aquifer is one to 3 years. A cross section of the disposal pond area showing the perched waste water zone as of 1961 is shown on Figure 54. The upper perched water covers an area of about 2.5 ha (6 acres). The perched water in the basalt covers about 1.3 sq km (0.5 sq mi) and has a maximum saturated thickness of 30 m (100 ft). The water table slopes laterally in every direction at a gradient away from the disposal pond. This perched-water body also contains seepage from the chemical and sanitary disposal ponds.

Tritium is the only radionuclide discharged to the ponds in large enough quantities and with sufficient half-life to be readily detected in the perched waste water. Figure 55 shows the extent of the perched water in the basalt and the tritium content in 1966. The amount of tritium discharged to the ponds from 1952 to 1966 was about 3,730 curies. Allowing for decay, about 2,730 curies would have remained by the end of 1966. About 20 curies was estimated to be in the perched water in the alluvium, 1,000 curies in the perched water in the basalt, and 100 to 600 curies in the Snake Plain aquifer. The Snake Plain aquifer receives radioactive waste water from the perched-water bodies and from the disposal well at the ICPP facility. Observation wells indicate two tritium plumes in the aquifer - a small one at the TRA facility and a large one in the ICPP area. Figure 56 shows the extent of the plumes. Most of this contamination is caused by discharge of radionuclides to the ICPP disposal well creating a waste plume of about 40 sq km (15 sq mi).

Nonradioactive hexavalent chromium, added to the cooling water as a corrosion inhibitor, is also discharged in wastes. From 1952 to 1963, the chromium wastes were discharged to the radioactive-waste seepage ponds. Since 1963, these wastes have been discharged to the TRA deep disposal well. Chromium serves as a good tracer of the TRA waste plume in the aquifer because the ICPP does not discharge chromium. In November 1966, hexavalent chromium concentrations in the Snake Plain aquifer below the TRA site ranged from less than 0.005 to 0.399 mg/l and averaged 0.060 mg/l. 125) This plume had moved 6.5 km (2.5 mi) south of the disposal pond, as mapped in 1970 and shown on Figure 56. According to J. B. Robertson of the U. S. Geological Survey, there appears to be no significant reduction of hexavalent chromium to lower oxidation states in the aquifer. Sorption does not appear to have a major effect on chromate migration.

Numerous studies of the migration and distribution of liquid waste discharged within the NRTS site have been made. These

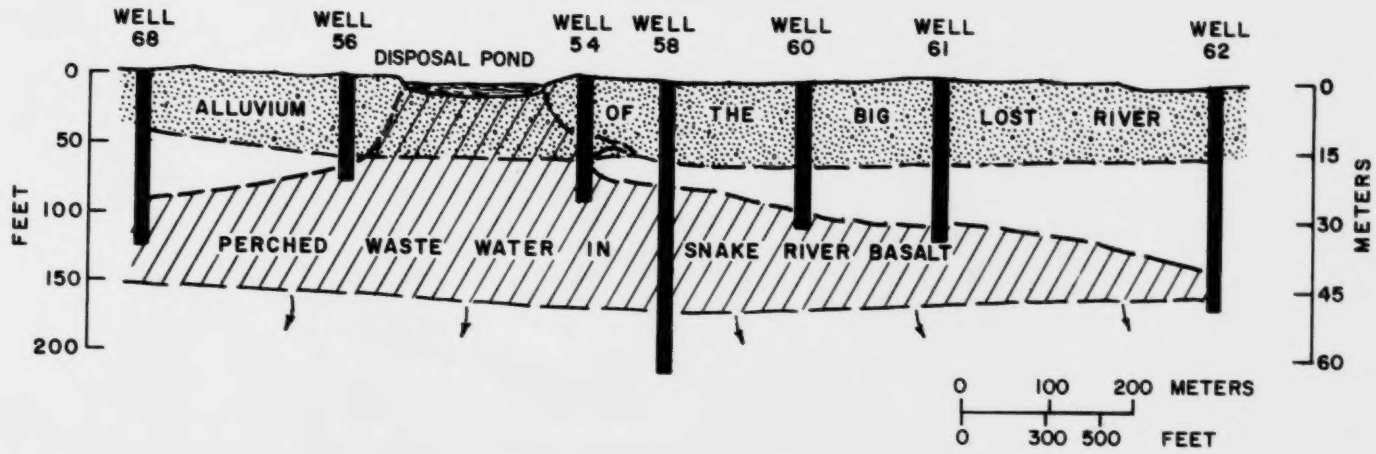

WELL 68
WELL 56
DISPOSAL POND
WELL 54
WELL 58
WELL 60
WELL 61
WELL 62
ALLUVIUM OF THE BIG LOST RIVER
PERCHED WASTE WATER IN SNAKE RIVER BASALT
FEET
0
50
100
150
200
METERS
0
15
30
45
60
0
100
200
METERS
0
300
500
FEET

Figure 54. National Reactor Testing Station, Idaho. Cross section of TRA disposal pond area showing perched waste water zone. 124)

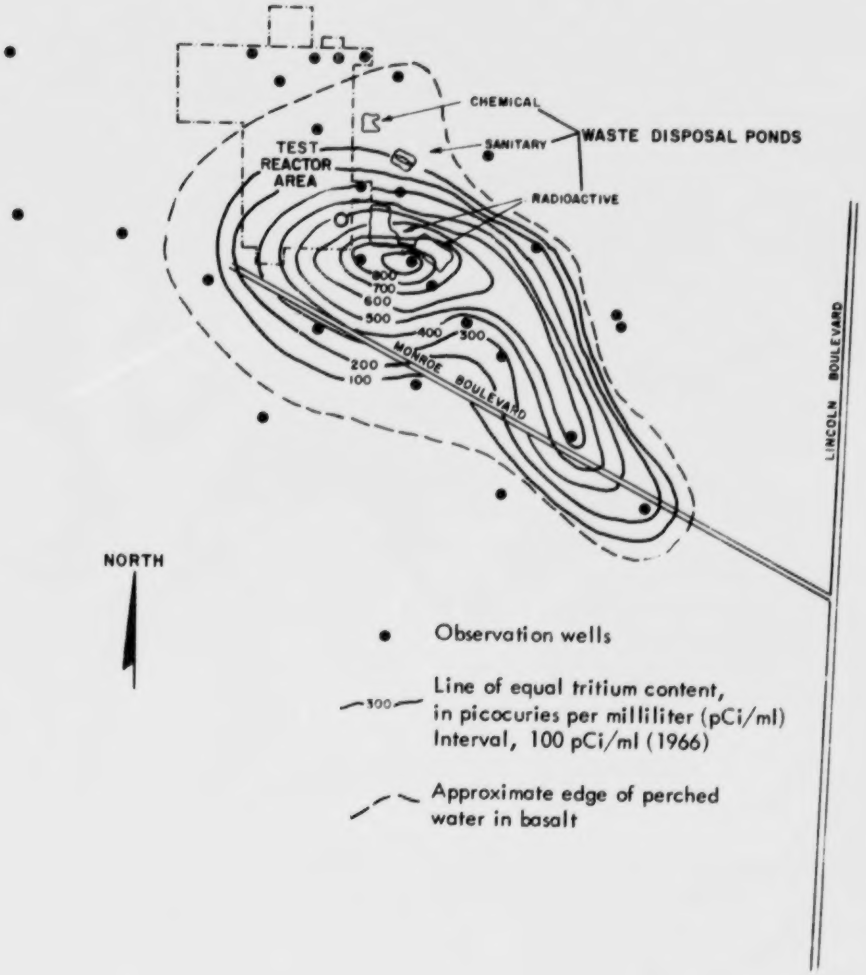

CHEMICAL
SANITARY
WASTE DISPOSAL PONDS
RADIOACTIVE
TEST REACTOR AREA
800
700
600
500
400
300
200
100
MONROE BOULEVARD
LINCOLN BOULEVARD
NORTH
Observation wells
300
Line of equal tritium content, in picocuries per milliliter (pCi/ml) Interval, 100 pCi/ml (1966)
Approximate edge of perched water in basalt

Figure 55. National Reactor Testing Station, Idaho Tritium content in perched waste water below the Test Reactor Area. 125)

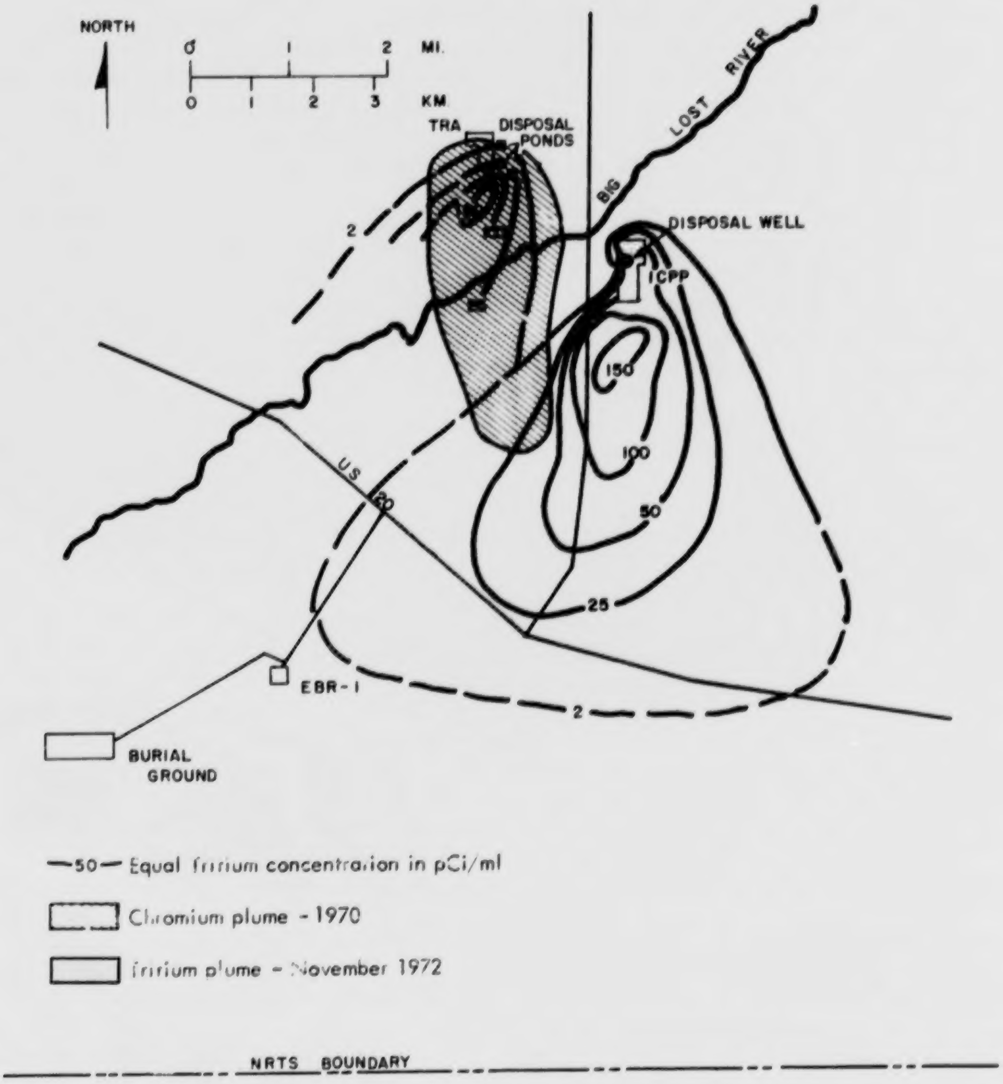

NORTH
0 1 2 MI.
0 1 2 3 KM.
TRA
DISPOSAL PONDS
BIG LOST RIVER
DISPOSAL WELL
ICPP
2
150
100
50
25
2
US 20
EBR-I
BURIAL GROUND
—50— Equal tritium concentration in pCi/ml
Chromium plume - 1970
Tritium plume - November 1972
NRTS BOUNDARY

Figure 56. National Reactor Testing Station, Idaho.- Distribution of tritium and chromium in the Snake River Plain aquifer at the ICPP and TRA facilities. 78, 125)

studies have been based on some 45 observation wells located near or downgradient from discharge areas. Robertson states that calculations for tritium indicate a nearly even quantity of 13,000 to 14,000 curies has been maintained since 1961 in the plume, and the decay rate about equals the long-term discharge rate. Thus, the total amount of tritum in the aquifer is not increasing, and since 1967, the quantity has decreased because of lower discharge rates. All tritium concentrations in the aquifer are well below the recommended guide of 3,000 pCi/l issued by the U. S. Atomic Energy Commission.

In addition to tritium and chromium, several other elements occurring in the discharge wastes have been used as tracers to map ground-water flow. These include chloride, sodium, Sr^{90}, and Cs^{137}. Chloride has been found to be the best tracer of waste behavior because it is discharged more constantly and in more uniform quantities than any other product. Also, chloride is relatively free from chemical reaction such as ion exchange or precipitation. The chloride plume closely resembles the tritium plume. The Sr^{90} plume is much smaller than the tritium and chloride plumes and occupies an area of about 4 sq km (1.5 sq mi). Cs^{137} is more affected by sorption than Sr^{90} and has never been detected in any aquifer near either the TRA or the ICPP facility.

In general, longitudinal and lateral dispersion of contaminants were found to be greater than expected from the classical theory of ground-water flow or from laboratory model studies. Vertical migration was found to be limited to the upper 75 m (250 ft) of the basalt aquifer due to lower vertical permeabilities. Digital model studies of chloride, tritium, and Sr^{90} migration made by Robertson appear to be a valid tool for predicting the travel of liquid waste in the aquifer. Forecasts for the various plumes show gradual growth but reduced concentrations as a result of dilution and dispersion.

The impact of these wastes on the environment surrounding the NRTS is constantly monitored by the NRTS Health Services Laboratory and results are published annually. As of 1972, none of the off-site well-water or surface-water samples contained any gross alpha, gross beta, or tritium activity above the detection limits of the analyses. 126)

Hanford Reservation

The Hanford Reservation, established in 1943, is the major disposal site of radioactive industrial wastes in the nation. A wide variety of radioactive wastes are generated by reactors and laboratories, and by the chemical processing of reactor fuels to extract plutonium. Liquid wastes are classed as low, intermediate, or high level. Low-level wastes contain less than 5 x 10^{-5} μCi/ml of radioactivity; intermediate-level wastes are between 5 x 10^{-5} μCi/ml and 100 μCi/ml of mixed radioactivity.

The most highly radioactive wastes are stored beneath terraces in tanks. As of 1969 there were 149 tanks, ranging in size from 190 to 3,800 cu m (50,000 to 1,000,000 gallons), buried beneath about 3 m (10 ft) of earth. These wastes contain long-lived radionuclides that will decay to a low-level of radioactivity in about 600 to 1,000 years. 127) Low- and intermediate-level liquid radioactive wastes are discharged into swamps, cribs, dry wells, and trenches. A typical swamp of 30 ha (77 acres) in size will accommodate a flow of about 30 million l/d (8 mgd). From the time of startup until 1967, 300 billion liters (80 billion gallons) of low-level waste containing 20,000 curies of beta activity have been released to swamps. 128)

The cribs are used primarily for the disposal of intermediate-level wastes and low-level wastes that are judged to have a high potential for contaminating the environment. Early cribs at Hanford were underground timbered structures filled with graded gravel. Current cribs consist of long, narrow trenches about 3 m (10 ft) wide at the bottom, filled with a few meters of graded gravel and covered by a plastic membrane (Figure 57).

The quality of ground water below the cribs is monitored by wells. When the long-lived radioactive materials, such as Sr^{90}, Cs^{137}, or Co^{60}, are detected in ground water in concentrations approaching 10 percent of the maximum permissible concentration for drinking water, the crib is removed from service. From the time of startup to 1967, 23 billion liters (6 billion gallons) of intermediate-level waste containing three million curies of mixed radioactivity have been released to cribs. Of this three million curies, only 500,000 curies remain within the soil due to continuous depletion by radioactive decay. 128)

Rock filled cavities or dry wells are similar in design to cribs, but are smaller in size and are located at relatively shallow depths. These are used for disposal of small quantities of low-level and intermediate-level wastes.

Intermediate-level wastes with poor or unknown soil adsorption characteristics are disposed of in liquid waste trenches constructed with conventional earth moving equipment. The trenches are managed in such a way as to prevent disposal of

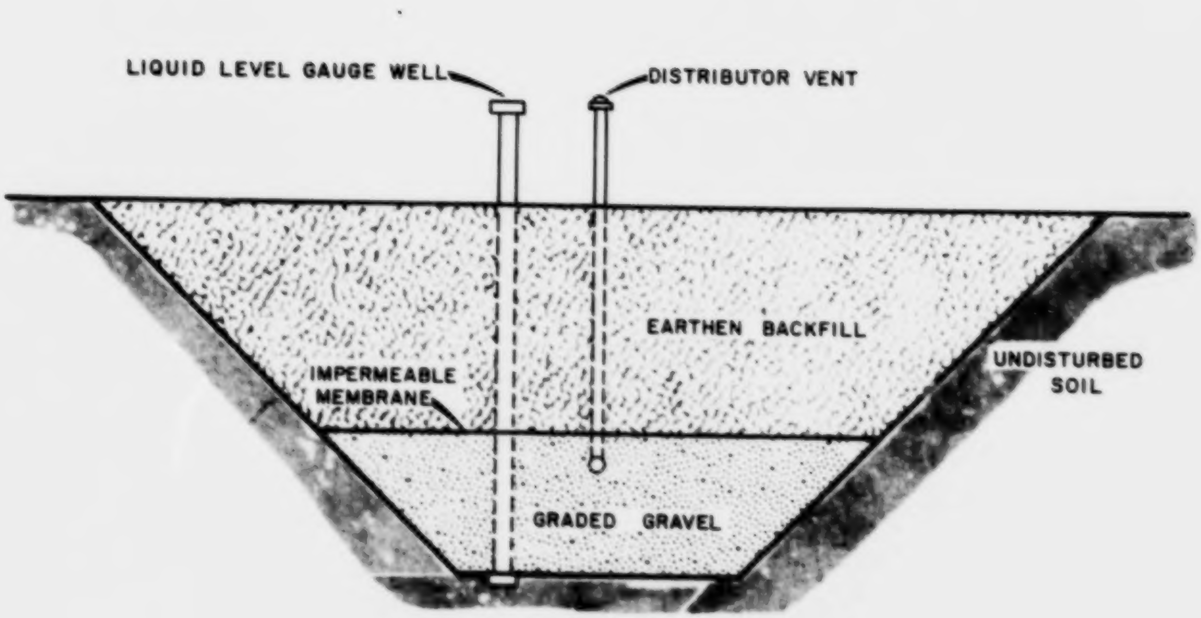

LIQUID LEVEL GAUGE WELL
DISTRIBUTOR VENT
EARTHEN BACKFILL
UNDISTURBED SOIL
IMPERMEABLE MEMBRANE
GRADED GRAVEL

Figure 57. Hanford Reservation, Washington. Cross-section of a typical crib. 128)

high-level wastes or liquid quantities that will exceed the adsorption capacity of the soil. Approximately 110 million liters (29 million gallons) of intermediate-level waste containing 660,000 curies of beta activity had been discharged to trenches until 1957, when this type of disposal was discontinued.

Solid wastes are classified according to handling requirements and radiation and are packed in cardboard, steel, wood, or concrete containers prior to burial. Monitoring wells are located in the burial area to detect any migration of leachate to the ground water. Underground caissons are used for wastes that are small in volume but high in activity level. These consist of concrete vaults into which drums containing waste are deposited. For large pieces of equipment, tunnels large enough to accommodate railroad cars are used to contain contaminated equipment.

The reservation is underlain by the Ringold Formation, a unit consisting of up to 360 m (1,200 ft) of silt, sand, clay, gravel, and some volcanic ash. This formation extends down to basalt bedrock. Glaciofluviatile deposits of sand and gravel have been deposited in channels eroded in the Ringold Formation. Ground water occurs under artesian conditions in the basalt and under water-table conditions in the unconsolidated deposits. The water table beneath the reactor areas lies at an average depth of 30 m (100 ft) and slopes toward the Columbia River. 129)

There are over 1,300 wells at the site, 300 of which are used for routine surveillance of radionuclide migration in the ground-water flow system. 128) Frequent sampling of wells is carried out and bi-annual reports are issued indicating the radiological status of the ground water. The locations of wells and plant facilities are shown on Figure 58. The ground-water contamination pattern beneath Hanford can be divided into three source zones based on the kinds and quantities of waste disposed to the ground at each location. The principal sources of liquid waste are the "200 Areas" of chemical processing plants in the center of the reservation. Then follow the six production reactor sites located adjacent to the Columbia River "100 Areas", and finally the fuel fabrication and laboratory area ("300 Area") in the southeast corner of the reservation.

Contamination at the "200 Areas" stems mainly from effluent disposed in cribs, swamps, and trenches. In the "100 Areas", radioactivity in ground water is due primarily to disposal of wastes in trenches and cribs, but leaks in reactor effluent systems have also contributed radioactivity to the ground

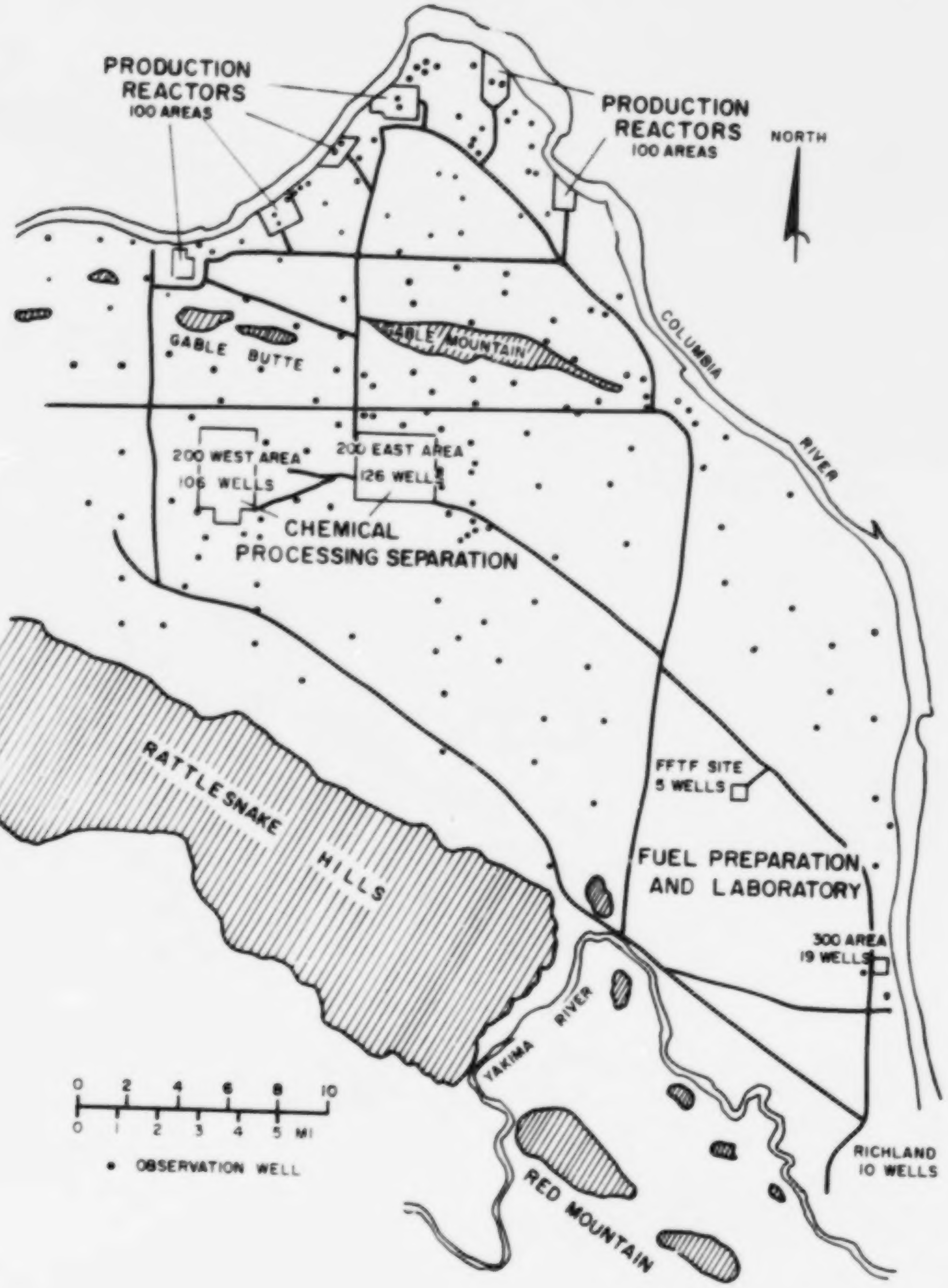

PRODUCTION
REACTORS
100 AREAS
PRODUCTION
REACTORS
100 AREAS
NORTH
COLUMBIA
RIVER
GABLE BUTTE
GABLE MOUNTAIN
200 WEST AREA
106 WELLS
200 EAST AREA
126 WELLS
CHEMICAL
PROCESSING SEPARATION
RATTLESNAKE HILLS
FFTF SITE
5 WELLS
FUEL PREPARATION
AND LABORATORY
300 AREA
19 WELLS
YAKIMA RIVER
RED MOUNTAIN
RICHLAND
10 WELLS
0 2 4 6 8 10
0 1 2 3 4 5 MI
• OBSERVATION WELL

Figure 58. Hanford Reservation, - Washington. Location of plant facilities and observation wells. 130)

water. In the "300 Area," disposal of low-level fuel processing wastes to two ponds has caused radioactive and nonradioactive contamination of ground water. 131)

Field studies at waste disposal sites have shown that essentially all the long-lived radionuclides adsorbed on the sediments in the unsaturated zone are retained in the sediment and are relatively immobile. Radionuclides which do eventually migrate downward into the ground water, with the exception of tritium, Ru^{106}, and Tc^{99} (Technetium-99), are quickly dispersed and diffused (and possibly resorbed) in the saturated zone. Radiochemical analyses of ground water show that within 1,000 m (3,300 ft) of the disposal sites, all nuclides except those noted cannot be detected using the most sensitive analytical methods. 132)

The radionuclides Ru^{106} and tritium, as well as the nitrate ion, are readily transported by the ground water and can be detected at low concentrations. These substances are therefore used to trace the movement of slightly contaminated ground water away from the major disposal areas. Tritium concentrations in ground water as of July-December 1972 are shown on Figure 59. 133) Concentrations are expressed as percentage of the tritium concentration guide (3,000 pCi/l) issued by the U. S. Atomic Energy Commission. 134) Several tritium plumes are shown, with the largest extending more than 16 km (10 mi) from the disposal sites and covering an area of about 80 sq km (30 sq mi). Contaminants are moving with the ground-water flow toward the Columbia River.

Nitrate concentrations in ground water are shown on Figure 60. Concentrations are expressed as percentages of the U. S. Public Health Service drinking water standard of 45 mg/l. Several nitrate plumes are shown; the largest plume coincides with the tritium plume. Nitrate concentrations in the plume range from 4.5 to 45 mg/l and are over 45 mg/l in the immediate disposal areas. As indicated by the extent of the plumes, in all probability, some radionuclides from the chemical processing areas are presently entering the Columbia River. However, the concentrations of these nuclides are too small to be routinely measurable in the ground water near the river or in the river itself, and radiation is deemed negligible by government scientists. 135)

Mathematical simulation studies are being carried out to predict the future distribution and movement of radionuclides in the saturated zone. 9) Also, studies of the deep aquifers are being made to monitor ground-water quality and assess the potential for deep-well disposal of highly radioactive waste fluids. 136)

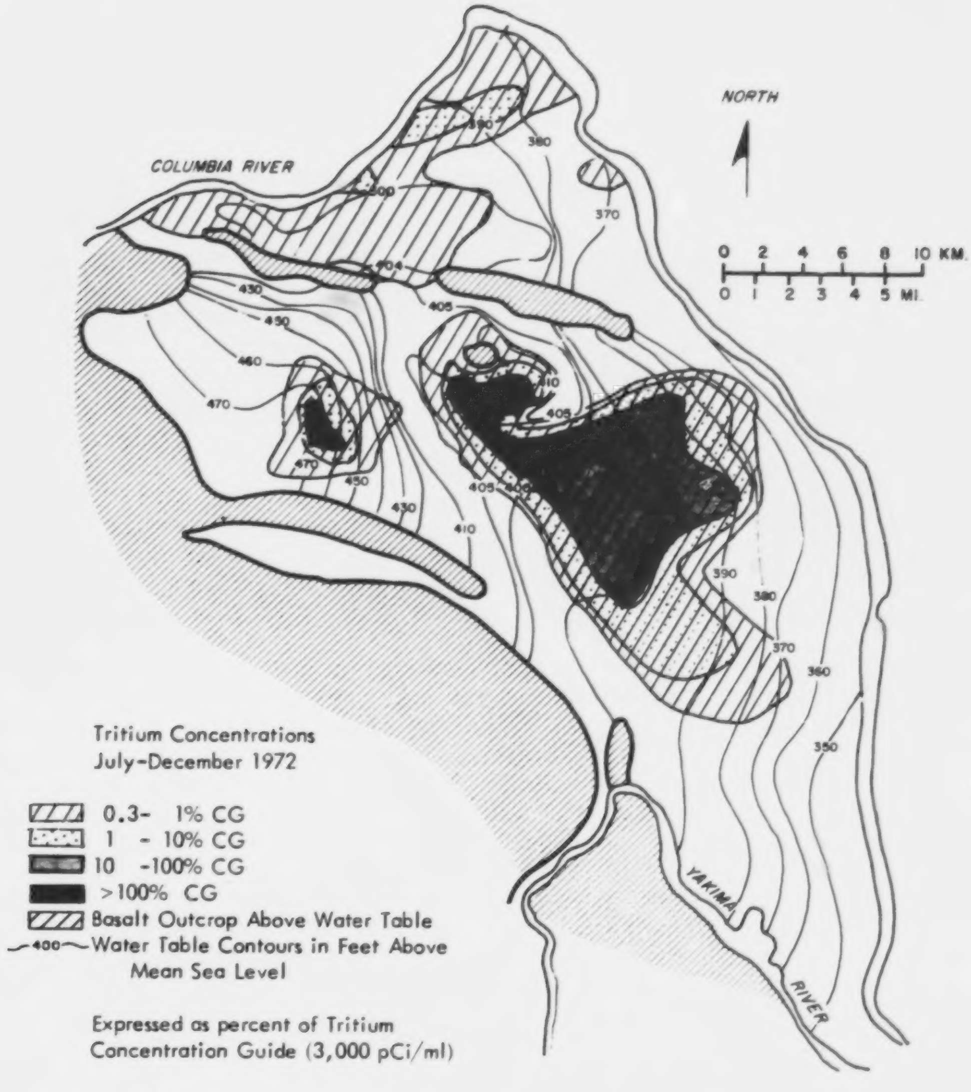

NORTH
COLUMBIA RIVER
0 2 4 6 8 10 KM.
0 1 2 3 4 5 MI.
390
380
370
400
404
405
430
450
460
470
410
405
470
450
430
410
405
400
390
380
370
360
350
YAKIMA RIVER
Tritium Concentrations
July-December 1972
▨ 0.3- 1% CG
▨ 1 - 10% CG
▨ 10 -100% CG
■ >100% CG
▨ Basalt Outcrop Above Water Table
400 Water Table Contours in Feet Above Mean Sea Level
Expressed as percent of Tritium Concentration Guide (3,000 pCi/ml)

Figure 59. Hanford Reservation, Washington. Tritium concentrations in ground water. 133)

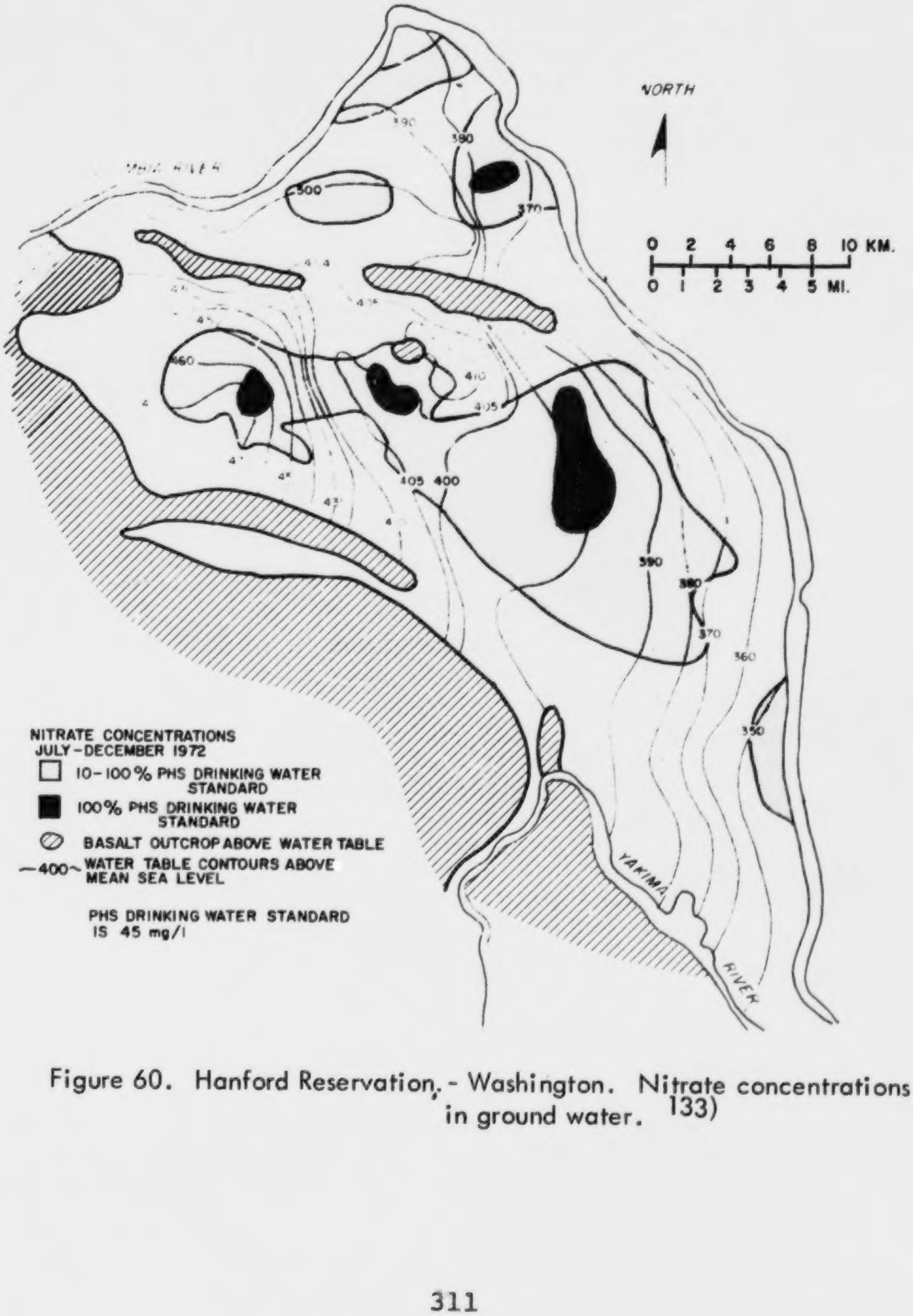

NORTH
0 2 4 6 8 10 KM.
0 1 2 3 4 5 MI.
RIVER
390
380
300
370
460
410
405
405 400
390
380
370
360
350
YAKIMA RIVER
NITRATE CONCENTRATIONS JULY-DECEMBER 1972
☐ 10-100% PHS DRINKING WATER STANDARD
■ 100% PHS DRINKING WATER STANDARD
▨ BASALT OUTCROP ABOVE WATER TABLE
—400~ WATER TABLE CONTOURS ABOVE MEAN SEA LEVEL
PHS DRINKING WATER STANDARD IS 45 mg/l

Figure 60. Hanford Reservation - Washington. Nitrate concentrations in ground water.133)

Rocky Flats, Colorado

Large amounts of tritium from a waste dump containing radioactive contaminants at the U. S. Atomic Energy Commission's Rocky Flats plant near Denver have leached into surface drainage and have ended up in the reservoir of a municipal water company. One sample collected by the Colorado Department of Health in September 1973 had a concentration of 40,313 pCi/l. Tritium concentrations in the reservoir were 10,000 pCi/l, approximately ten times the normal tritium background in Colorado. 110) The hydrologic and health aspects of this problem are now under investigation by the U. S. Geological Survey and the Colorado Department of Health, respectively.

Oregon

In Oregon, some radioactive waste was dumped at a disposal site in Gilliam County. A geological study of the disposal site was made by an engineering firm, and an investigation of ground-water quality was presumably undertaken. 31)

SPILLS AND LEAKS

Spills or leaks of liquid waste on or below the land surface from breaks in pipelines, tank truck accidents, and failure of gasoline tanks or other storage tanks, can cause degradation of ground-water quality.

Toxic wastes and hydrocarbons can enter the ground and percolate to the water table, then move with the ground water to a point of discharge, such as a pumping well or a river or stream. Breaks in underground pipelines or tanks often go undetected for months or years. Frequently, the only indication of a leak or loss of fluid comes from comparison of measured volumes pumped, stored, or extracted. When unexplained losses of fluids become apparent, a search for leaks is generally undertaken. Upon discovery of leaks or spills, recovery of the lost liquid is rarely feasible.

Case Histories

Spills and leaks of petroleum products during transport and storage are the most common of all reported incidents. Leaks of gasoline from storage tanks at service stations were mentioned by officials in all states in the Northwest. Pipeline breaks and truck and railroad tank car accidents also account for a large number of leaks and spills. In the state of Washington, 1,400 oil spill complaints were reported in the two-year period of 1970 to 1972. 122) Of these, only eight presented a definite threat to ground-water supplies.

In Wyoming, three small businesses were forced to close because of gasoline that had entered the basements of their premises. 137) The gasoline had migrated to the water table from a leaky storage tank at a nearby service station. To remove the gasoline and the danger of explosion, a large area was excavated, and the thousands of gallons of contaminated water were removed.

In Colorado, gasoline leaks are recorded on a monthly basis by the State Oil & Gas Inspection office. 138) During one month, as much as 140,000 liters (37,000 gallons) from various sources leaked into the subsurface. These spills are being mapped for the purpose of determining high incidence areas. It appears that certain soil types in some areas are more corrosive than others, causing failure of storage tanks. In addition, salts used for deicing of service station areas are thought to have increased the corrosiveness of the soil. An interesting discovery was the fact that service stations along streets that formerly had electric street car routes tend to have a higher incidence of leaks from storage tanks. This is believed to be caused by electrolytic corrosion of tanks along these routes. Attempts are currently being made in some states to draft corrosion protection laws for storage tanks. Some oil companies and operators are changing over to fiberglas tanks or other corrosion resistant materials in anticipation of such action.

During the first six months of 1973, the Department of Ecology of the state of Washington recorded nearly 500 complaints of oil spills, only a few of which affected ground-water supplies. Of these spills, 213 were from unknown causes, 63 were directly attributed to human error, and the remainder were due to such things as poor maintenance, deliberate dumping, or equipment failure. 139)

Leaks and spills of petroleum products from several tank farms in Idaho caused contamination of nearby domestic water wells. 140) Spills at an oil refinery at Billings, Montana, entered the ground water and discharged into the Yellowstone River. 27) Spills at a refinery at the port of Pasco in Washington have also caused ground-water contamination, and in Colorado, refueling operations at railroad yards have been found to contribute to ground-water and surface-water contamination. 34,141)

In Montana, ground-water contamination from gasoline spills has taken place in the town of Missoula. Two spills, each of 3,800 to 7,500 liters (2,000 to 3,000 gallons) of gasoline, occurred in recent years forcing the abandonment of several water wells. A similar problem occurred in the town of Deer Lodge, where a municipal well became contaminated with gasoline. The problem was solved by lining the well, excavating the leaky tank, and installing a drain system to hold the water table at a constant elevation. 27)

In Oregon, the State Engineer's Office receives reports of one to two gasoline spills per year. 30) Contamination of the ground-water supply by diesel fuel at the town of Pendleton has occurred. This took place when a railroad tank car accidentally spilled a load of diesel fuel over the infiltration gallery of the town's water system. 32)

Oil pipeline companies are required by federal regulations to submit reports on oil spills when more than 2,000 liters (50 barrels) of liquid are lost. In 1969, a total of 29 such spills was recorded by the U. S. Department of Transportation. Thirteen incidents took place in Wyoming, ten in Montana, four in Colorado, and two in Idaho. 142)

A large spill occurred in the Bellingham area of Washington when a rupture occurred in a crude oil line and one million liters (300,000 gallons) of crude oil spilled on the ground. Fortunately, the break occurred on terrane underlain by glacial till of low permeability, and oil did not penetrate to deeper zones. The clean-up operation consisted of excavating the contaminated soil. 139)

Leaks and spills of radioactive liquid wastes have taken place at the NRTS and the Hanford Reservation. Many leaks occurred because of corrosion and failure of buried waste lines. 143) A serious leak took place at Hanford in June 1973 when failure of a steel tank caused the release of over 400,000 liters (115,000 gallons) of high-level radioactive wastes. To investigate the impact of this leak, 16 wells were drilled around the tank. Core samples indicated that the lateral extent of the liquid contaminant was elliptical, extending from 33 to 45 m (110 to 150 ft) from the tank center. The maximum vertical penetration was 26 m (86 ft) below ground level and 35 m (116 ft) above the regional water table. The leakage was found to constitute no threat to public health at the time of the investigation. Monitoring data showed that the radioactivity had been retained in the soil above the water table. It was determined that a driving force to move the contaminant toward the ground-water system did not exist. In addition, the investigators found that the radioactive elements that might eventually reach the water table would decay to a harmless level in the time required for the contaminant to reach the Columbia River. 144)

FERTILIZERS AND PESTICIDES

Commercial chemical fertilizers used for improving crops contain phosphates, nitrogen, and other plant nutrients. Nitrates in water in excessive concentrations may cause methemoglobinemia in infants, and for this reason the U. S. Public Health Service standards limit the nitrate content of drinking water to 45 mg/l. Cattle are also susceptible to nitrate toxicity.

Application of fertilizers on the land surface has greatly increased on a national basis, from 300,000 metric tons of nitrogen in 1940 to almost 6.7 million metric tons in 1970. 145) For 1970, total fertilizer use in the Northwest was 1.7 million metric tons of which about 330,000 tons consisted of phosphates. Most of the fertilizer was used in Washington, Oregon, and Idaho (see Table 42). Although a large amount, the fertilizer use in the Northwest is only about 5 percent of the national use. In comparison, total fertilizer use in California alone was 2.6 million metric tons. Study of nitrates as a source of ground-water pollution is complicated by naturally occurring nitrogen in soils and nitrates contributed from domestic sewage effluent and animal wastes. 146,147)

Pesticides applied to crops and soil can enter the ground-water system in several ways. Toxic contaminants can infiltrate the soil and migrate to the zone of saturation or they can mix with surface runoff and enter the aquifer through unprotected or poorly constructed water wells. The rate of migration of the pesticide and subsequent contamination of the ground-water reservoir is dependent upon the type of pesticide and the nature of the soil. Soluble pesticides, such as 2,4-D are a larger threat to ground water than relatively insoluble and immobile pesticides such as aldrin, dieldrin, and DDT. 148)

Case Histories

An intensive study of soil profile and ground-water quality was carried out in the South Platte Valley of Colorado. 149, 150) Cores were taken to the water table at 129 locations, and cores and water samples were analyzed for nitrate content. The average nitrate content in the soil profile varied greatly, but there was little difference in the nitrate content of the water (Table 43). Calculations based on average nitrate content of the irrigated fields (excluding alfalfa) and the rate of water moving through these profiles suggested that 28.2 to 33.6 kg of nitrogen per hectare (25 to 30 lbs per acre) was lost annually to the water

Table 42. CONSUMPTION OF COMMERCIAL FERTILIZERS IN 1970. [145)]

	Total fertilizers		Of which phosphates	
State	Short tons	Metric tons	Short tons	Metric tons
Colorado	257,898	233,965	27,815	25,234
Idaho	423,206	383,932	99,909	90,637
Montana	178,644	162,066	73,620	66,788
Oregon	440,292	399,433	110,905	100,613
Washington	541,645	491,380	48,236	43,760
Wyoming	60,984	55,325	8,363	7,587
Total:	1,902,669	1,726,101	368,848	334,619

Table 43. CHEMICAL ANALYSES OF GROUND WATER BENEATH FEEDLOTS AND ADJACENT IRRIGATED FIELDS IN THE SOUTH PLATTE VALLEY OF COLORADO. [151)]

	Core No.	Depth to water table (m)	NO_3-N (ppm)	NH_4-N (ppm)	Organic C (ppm)	P (ppm)	Redox potential (mv)
Feedlot	7-E	10	8.6	5.1	130	0.25	- 340
Irrigated field	7-B	10	0.1	0.0	18	0.06	300
Feedlot	9-F	5	18	5.7	130	0.36	- 310
Irrigated field	9-C	3	31	0.1	12	0.04	360
Feedlot	9-E	4	21	5.8	90	0.22	340
Irrigated field	9-J	3	8.5	0.0	9	0.01	430
Feedlot	16-B	11	1.1	38	170	1.3	100
Irrigated field	16-D	11	18	0.4	26	0.05	430

table. 151)

There is very little documented data of ground-water pollution caused by fertilizers and pesticides. However, concern has been expressed about infiltration of these potential pollutants in the zone of recharge of the Ogallala Formation in eastern Colorado. In the San Luis Valley of Colorado, heavy application of chemical fertilizers is the probable cause of high nitrate concentrations (in excess of 45 mg/l). 152) In the same valley, some irrigators reportedly use siphons on pumps to distribute liquid fertilizers with the irrigation waters. When pumps are turned off these siphons can let fertilizer flow into the well and into the aquifer. 153)

High nitrates have been attributed to heavy fertilizer applications in the major river valleys of Washington State. These include the Columbia, Yakima, and Colville River basins. 154 through 157) Almost all counties in Washington in which heavy irrigation and fertilizer application take place have reported a high incidence of nitrate contamination; however, the degree to which these reported cases are directly related to fertilizer application is unknown. 33) The Washington State Department of Ecology reported only one incident of water pollution from fertilizer use in 1970, none in 1971, three in 1972, and none in the first six months of 1973. 122,139) Of all of these incidents only one was a ground-water problem, and this was due to careless handling by an industrial supplier.

High nitrates recorded in the alluvial aquifer of the Kalispell Valley in northwestern Montana are believed to be derived from heavy application of commercial fertilizers. 158) However, other sources of high nitrates such as feedlots and septic tanks are also mentioned as possible causes.

Over 680 water samples from surface water and ground water were tested to determine the effect of irrigation agriculture on water quality in the Boise Valley in southwestern Idaho. 159) Most of the farms in this area are gravity irrigated, and water application efficiencies are fairly low. The water table is close to land surface, and many soils in the valley contain clayey beds which limit downward water movement. The ground water was found to contain more nitrate-nitrogen than other water sources, a possible result of leaching of nitrate from the soil by percolating irrigation water or contribution from feedlots, dairies, and septic tank drain fields. Ascertaining the actual nitrate sources turned out to be difficult as the water table was close to the ground surface. The ground water was also found to contain a relatively large concentration of both ortho and total phosphorous (0.11 and 0.58 mg/l respectively).

The cases of ground-water contamination by pesticides mentioned most frequently by county and state officials were those resulting from accidental spills in the vicinity of a well or into an irrigation canal with subsequent leaking of the contaminant to the ground water. Potential problems from pesticide container disposal was the next most-mentioned problem. An example of ground-water contamination from actual application of pesticides was reported in northwestern Oregon where shallow alluvial wells were found to be contaminated with arsenic, believed to be derived from pesticide spraying in orchards. 120,160)

Canyon County in southern Idaho uses large quantities of pesticide. No documented cases of ground-water contamination have been reported as yet, but many public agencies in the state are concerned about the potential effect. 161) The main problem in this area seems to be accidental spills which occur each year during the peak-use period. In the Idaho Falls area, there was a period of heavy use of dieldrin for control of Weiss worm in potatoes. Although dieldrin is no longer used, the pesticide will persist for some time in the soil and presents a potential problem.

FEEDLOTS

Cattle feedlots generate a large amount of solid and liquid waste that is deposited on the land surface. One steer in a feedlot produces about one cu m (34 cu ft) of manure in one year. A feedlot with 1,000 head of cattle produces 956 cu m (1,250 cu yd) of manure per year. In terms of BOD (biochemical oxygen demand), each animal produces an amount of waste equivalent to six people. A feedlot of 1,000 head on about 4 ha (10 acres) of land produces wastes equal to that from a town of 6,000 people. 162) One large feedlot in Greeley, Colorado, handles over 100,000 head, and it has been estimated that the waste produced at this facility is about the same as from a city of one million people. 163) Some of the constituents of the waste from a 1,000 pound bovine on a daily and 140-day feeding period basis are given in Table 44. Also given are the annual wastes produced by 360 head per acre.

The number of feedlots in the six states and their capacities are shown in Table 45. The total number of feedlots has declined from 4,610 in 1963 to about 2,452 in 1973. However, the number of feedlots with a capacity of over 1,000 head increased from 263 to 392 in the same period. The

Table 44. SOME OF THE CONSTITUENTS OF WASTE FROM A 1,000 POUND BOVINE. 163)

	Per day (lbs) a)	140 days (lbs)	360 head/acre per year (tons)
Wet manure and urine	64	8,960	4,200
Dry mineral matter	2.1	294	144
Dry organic matter	8.2	1,148	540
Water	53.7	7,518	30.7 inches
Total nitrogen	0.38	55	24.9
Total phosphorous	0.048	6.7	3.2
Total potassium	0.26	36.4	16.8

a) one lb = 0.454 kg

Table 45. NUMBER AND CAPACITY OF FEEDLOTS IN THE NORTHWEST. 164)

	Under 1,000 head	1,000 to 1,999	2,000 to 3,999	4,000 to 7,999	8,000 to 15,999	16,000 to 31,999	32,000 and over	Number of lots over 1,000 head	Total all feedlots
Colorado									
1963	1,200	25	26	15	14 a)	-	-	80	1,280
1973	426	66	51	25	18	19	4	183	609
Idaho									
1963	820	36	13	11 a)	-	-	-	60	880
1973	492	26	22	15	13 a)	-	-	76	568
Montana									
1963	574	17	6	3	-	-	-	26	600
1973	236	31	20	11	7 a)	-	-	69	305
Oregon									
1963	536	25	11	9	-	-	-	45	581
1973	310	8	10	4	4 a)	-	-	26	336
Washington									
1963	579	19	11	6	3	-	-	39	618
1973	165	6 a)	-	10 a)	-	5 a)	-	21	186
Wyoming									
1963	638	9	4 a)	-	-	-	-	13	613
1969	-	-	-	-	-	-	-	17	448

a) Lots from larger size groups are included to avoid disclosing individuals.

largest number of feedlots is in Colorado, where 19 feedlots fall within the 16,000 to 31,999 head capacity, and four have a capacity of 32,000 or over. 164)

Feedlot wastes are leached and washed away as the manure decomposes. Runoff containing excessive quantities of nitrogen, phosphorous, potassium, and pesticides can enter surface-water drainage systems. Buildup of constituents such as nitrate in ground water results from direct percolation through the feedlot, and percolation through waste disposal areas and fields spread with manure. Organic materials and coliform bacteria normally do not reach the water table. A study of nitrates in Colorado (see Table 43) showed that concentrations of nitrate below feedlots ranged from none to over 5,000 pounds of nitrogen per acre across a 20-foot profile. If all the nitrate from a one-acre feedlot containing this high level of nitrate leached into the ground water, it would raise the nitrate content of approximately 200 acre-feet of water to 10 mg/l nitrate-N, the maximum safe drinking water limit set by the U. S. Public Health Service. 151) However, denitrification was found to occur under feedlots, and consequently it was believed that much of the nitrate never reached the water table.

Documented cases of ground-water pollution due to feedlot leachate are rare. Many cases of high nitrates in ground water result from poor construction of water wells. Corroded or perforated surface casing and lack of proper cementing of wells allows pollution from surface sources to take place. In northeastern Colorado, some stock water wells near feedlots had to be abandoned because the water was unsuitable even for livestock. 163) These feedlots were located on alluvial fill material, the principal aquifer in the area. Recently, the Colorado Department of Health denied a feedlot permit to a company because it found that the operation would cause contamination of shallow ground water. 165) The U. S. Geological Survey in Colorado has initiated hydrogeologic studies of potential feedlot sites. 166)

In Washington, many feedlots are believed to contaminate ground water. The source of high nitrates is not clear as many feedlots are located in areas of high septic-tank usage. Most of the feedlots are located in the Yakima Valley and the Columbia Basin.

In Idaho, feedlots are located mainly along the Snake River from Idaho Falls to Weiser. Feedlots, together with manure pits on dairy and chicken farms, are considered potential hazards and are under study by the University of Idaho, the

Idaho Department of Environmental and Community Services, and the U. S. Corps of Engineers. 167)

SALT-WATER INTRUSION

Coastal aquifers can be in contact with sea water, and under natural conditions, fresh ground water is discharged into the ocean. If, however, pumpage of ground water is sufficiently large, the seaward flow of ground water decreases or reverses causing sea water to advance inland into aquifers. This phenomenon is called sea-water intrusion.

Relatively few cases of sea-water intrusion occur in the Northwest, and it is not a major problem. More frequent are cases of upward migration of saline water in inland areas. The latter situation can develop where saline ground water underlies fresh-water aquifers. Problems of this type were discussed in Section V.

Case Histories

A survey of sea-water intrusion along coastal Washington was made in the period 1966-68. 168) It was found that near the Pacific Ocean and along most of the shoreline of the Strait of Juan de Fuca, development of ground-water supplies was localized, and in only a few cases did salt-water intrusion affect more than one or two wells at any particular locality. Intrusion along shorelines of Puget Sound is more pronounced because of more intensive development of ground-water supplies on the many islands and long, narrow peninsulas which are readily susceptible to intrusion. Cases of sea-water intrusion have been reported near Olympia, at Tacoma, in northern Kitsap and northeastern Jefferson Counties, and in Island County.

The situation in Washington is often complex, as many occurrences of saline ground water in the coastal area are probably due to "relict" sea water or connate water that has been in the aquifer since deposition of the sediments.

A small public supply system serving 25 homes in a subdivision adjacent to Puget Sound experienced salt-water intrusion in their supply well. 169) Six other wells tapping the same aquifer and serving about 200 homes were not affected.

Three public supply wells at Hyada Park, north of Tacoma, were contaminated by sea water. Chloride content in the wells was found to increase progressively during heavy pumping in summer. Concentrations of chloride in wells ranged up to 1,000 mg/l. An investigation by the U. S. Geological

Survey showed that the vulnerability of the site to sea-water contamination was related to a low rate of recharge. Although precipitation was abundant - 800 to 1,600 mm or 32 to 64 inches per year - the low permeability of glacial till mantling the upland area limited recharge to the aquifer. 170)

In Oregon, sea-water contamination has occurred in the coastal region of Tillamook and Clatsop Counties. Four water wells were found contaminated, two of which were heavily pumped industrial wells located adjacent to Taylor Bay. 171)

Upconing of saline water into fresh-water zones has occurred in Oregon where saline water in sedimentary rocks underlying basalts migrated upward. 39,172,173) Pumpage of a well and lowering of the hydrostatic head caused saline-water intrusion in Portland. 174)

HIGHWAY DEICING SALTS

Each winter, highway departments apply salts (sodium chloride and calcium chloride) to their road networks to eliminate or control ice and snow. In many states, problems stemming from this practice have now begun to show up, and there is an increasing concern about the environmental dangers caused by salt to vegetation, soil, and water supplies. Deicing salts contaminate surface runoff, ponds, streams, and ground water, principally near roadside areas. Substances added to deicing salts to prevent caking or to inhibit corrosion, such as sodium ferrocyanide and phosphorous compounds, can be extremely toxic to human, animal, and fish life. Deicing salts are potentially more harmful in arid regions where less precipitation and less dilution take place.

The use of deicing salts in the Northwest in the winter of 1966-67 is shown in Table 46. The total of 14,500 metric tons of sodium chloride is very small compared to use of deicing salts elsewhere in the nation. 175) For example, the state of Massachusetts alone has used 172,000 metric tons of sodium chloride in a single winter season. Nevertheless, because of low precipitation and low flushing and dilution in the arid zone, deicing salts can be a contributing factor in deterioration of ground-water quality.

MASS BURIAL OF LIVESTOCK

Perhaps the least common and least documented potential hazard to ground-water quality is mass burial of livestock. Large numbers of stock sometimes die because of infectious

Table 46. USE OF DEICING SALT (SODIUM CHLORIDE) IN THE NORTHWEST IN THE WINTER OF 1966-67.[175]

State	Short tons	Metric tons
Colorado	7,000	6,350
Idaho	1,000	907
Montana	4,000	3,629
Oregon	1,000	907
Washington	2,000	1,814
Wyoming	1,000	907
Total:	16,000	14,514

disease, such as blackleg or hoof rot, or because of a severe winter storm. The common practice of disposal is to bulldoze a large pit and bury the carcasses. In Glacier County and western Pondera County on the Blackfeet Indian Reservation, an estimated 500 head of cattle died in a severe winter storm and were buried in dug pits at various locations. 176)

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SECTION VII

RESEARCH AND OTHER NEEDS

TRENDS IN GROUND-WATER POLLUTION

Prior to examining research requirements for assessment, control and monitoring of ground-water pollution, it is necessary to review trends in subsurface contamination and identify potential sources of such pollution. The two factors that may greatly influence patterns of contamination of ground water are the expanding population in the urban zones and the expected large-scale mining of oil shale and coal to develop new sources of energy. The rise in urban population will result in an expansion of the number of sewage treatment plants and a corresponding increase in effluent discharge to surface-water bodies. In the arid zone, this may cause a further decline in the quality of stream water. As recirculation takes place through irrigation, the ground-water quality may also be affected. In the non-sewered areas, an increase in population will result in more septic tank construction. Especially in the mountain areas, pollution of ground water from septic tank effluent will increase.

Mining of oil shale and coal is a potential hazard to ground-water quality because of leaching of waste piles and acid drainage from strip-mined lands. Proposed coal gasification or liquification plants will require large quantities of demineralized water, and the brine produced must be disposed of either in impoundments or by deep-well injection.

Drilling of deep exploratory oil, gas and water wells will continue probably at an increasing pace in view of the present energy crisis, and so will potential ground-water pollution from improperly sealed holes. Fewer geophysical test holes will be drilled in the future because geophysical companies are shifting to surface energy systems that require fewer shot holes. Laws requiring proper plugging of abandoned wells have been enacted in Colorado, Montana, and Wyoming, but only with strong inspection and enforcement will this potential source of contamination be reduced.

The number of landfills for municipal and industrial waste will increase, but these waste disposal sites are now under close scrutiny by state environmental and health departments. Proper engineering design of waste dumps and monitoring of ground-water quality and leachate production will tend to reduce the incidence of ground-water pollution.

According to the Federal Water Pollution Control Act Amendment of 1972, discharge of toxic pollutants by industry will be controlled by effluent standards set by the Environmental Protection Agency in 1974, and industries must use the "best practicable" water-pollution control technology by July 1, 1977. Because of this legislation, industry is moving from direct discharge of waste liquids into rivers and streams to impoundments. Leakage from unlined storage basins poses a threat to ground-water quality. This problem is expected to increase considerably in future years along with the potential for ground-water pollution from land treatment of municipal and industrial waste waters.

In the agricultural sector, the demand for more food and larger crops will result in large applications of both fertilizers and pesticides. Irrigated agriculture in the arid zone will cause a continuation of build-up of salts in the subsurface. Proper drainage and irrigation management are tools needed to halt this trend. The saline seep problem in dryland areas of Montana and adjacent states is serious and may be expected to increase. Change in crop patterns and farming practices may be needed to control this ground-water pollution problem. Feedlot operations appear to be shifting to fewer lots but higher capacities. Contamination of shallow ground water from existing feedlots will continue, but the problem will probably decrease in future years due to stricter governmental control. State and federal agencies are actively reviewing potential pollution problems from proposed new feedlots.

Radioactive waste disposal will decrease at some installations as reactors are phased out. Leaks and spills, however, will continue to be a serious source of ground-water pollution, and the number of such incidents is expected to grow along with increased population and industrial activity.

GENERAL RESEARCH NEEDS

A general need for proper assessment and control of ground-water contamination is basic information on geologic and hydrologic conditions, water quality and identification of sources of ground-water pollution. As of 1965, only approximately 40 percent of the Northwest had been covered by reconnaissance or general ground-water investigations, and only 5 percent by detailed evaluations. In recent years, there has been a considerable increase in ground-water investigations on both state and federal levels but ground-water conditions over large portions of the study region remain essentially unknown.

This lack of data is also reflected in the quantity and type of data on water quality. There is a distinct lack of baseline water-quality data and a definite need for preparing this type of information so that degradation of water quality can be detected in the future. Laboratories should be set up on a regional or county basis and ground-water and surface-water sampling and analysis should be carried out on a regular basis. In addition to routine analyses, trace constituents should be checked periodically to detect organic and inorganic compounds and to identify particularly harmful pollutants, such as carcinogens. These analyses should be standardized so that water quality can be more readily compared from one area to another.

Standardized methods for reporting and collecting data on incidents of ground-water pollution should be developed so that cases can be quickly evaluated and remedial action can be taken immediately to correct the situation. Perhaps a computer printout system of pollution incidents similar to that in use by the Department of Environment in Washington would be useful in the individual states.

State governments should set aside a larger portion of their financial resources for the protection of ground-water resources. This will enable administrators to acquire the necessary professional staff and to plan and carry out ground-water quality investigations. At the present time, the staff and personnel in charge of ground-water resources in several states are solely administrators of water rights and either have no authority to investigate cases of ground-water contamination or have insufficient personnel to make thorough investigations. Most departments have no field inspection team to monitor compliance with existing regulations regarding construction and abandonment of wells. In some cases, the responsibility for investigation of ground-water pollution is not clearly defined between state agencies.

There is also considerable reluctance on the part of many state and county officials to discuss pollution problems. In the future, with better administration and coordination, the various officials should cooperate and share their information freely. For the above reasons, information on ground-water pollution is difficult to obtain. It is virtually certain that only a very small percentage of the existing problems have been discovered to date. The impact of the oil and gas industry, for example, on ground-water quality is essentially unknown. There is a definite need to study oil-field regions and injection systems to assess the potential hazard of brine or waste injection to fresh-water aquifers. It is true that much industrial development is taking place in sparsely populated areas, but in the arid zone fresh ground water is difficult to develop and measures should be taken to protect such aquifers from degradation to insure their availability to meet future needs.

Further investigations to inventory and evaluate ground-water contamination should be a major concern of public water-resources agencies. Perhaps each agency can start to inventory, for example, each industrial waste-disposal site, sewage lagoon, mine tailings dump, landfill operation and oil pipeline. Aerial photographic techniques, including remote sensing and multispectral photography could be useful for this purpose. Records of flow and discharge of waste effluent could be assembled so that potential problems can be more easily evaluated. To deal with existing problems of ground-water contamination, standard techniques call for the drilling and testing of monitoring wells, and collection of water samples. Installation of such wells is by far the most expensive part of any investigation, and research is needed to devise better and more economical methods for obtaining subsurface information. Additional research in geophysical techniques could probably refine the present mapping techniques to obtain better definition of bodies of liquid waste below land surface.

After the initial evaluation of polluted ground water has been made and the hydrologic environment has been established, measures can be taken to contain the contaminants and prevent them from further spreading in the aquifer zone. This containment could be carried out by manipulation of hydraulic gradients through controlled pumping operations; by prohibiting or restricting pumping in a specified zone surrounding the contaminated area; or by physical containment by means of artificially injected hydraulic barriers.

Removal of contaminated ground water by pumping or excavation is generally undertaken, although it is rarely possible to completely eliminate the pollutant. Research on better methods to remove such pollutants as hydrocarbons from the unsaturated and saturated zone is certainly warranted.

Obviously, the best way to reduce future cases of ground-water contamination is through education of the general public and through legislation and enforcement of regulations. There is an urgent need to acquaint the public with the serious consequences of ground-water pollution and the large financial expenditures required to contain or remove underground pollution.

SPECIFIC NEEDS

An attempt has been made in Table 47 to assign research and control priorities to the various sources of ground-water contamination. Some of these sources have been already studied for many years. For example, radioactive waste disposal has received a great deal of attention in the past two decades and a considerable amount of research on the impact on ground water has been, and still is, carried out. Research needs for this source of ground-water contamination are thus rated as less important at this time than other sources that have been studied to a lesser degree, such as those related to sewage effluent, agricultural practices, brine injection and surface impoundments.

Septic Systems

1. Improve septic-tank system design to provide better treatment.

2. Initiate land-use management techniques that emphasize protection of ground-water quality from the effects of on-site waste disposal systems.

3. Require regional hydrogeologic reports providing such data as depth to bedrock, major joint patterns, soil conditions, and aquifer characteristics in order to assist in evaluation of permit applications for septic systems, where large-scale community development is proposed.

Sewage Treatment Plant Discharge

1. Continue research on the travel, dispersion and fate of organic and inorganic constituents in sewage-plant effluent and surface water under conditions of river infiltration in the semi-arid zone.

2. Study hydrogeological conditions downstream of individual sewage plant discharges to assess possible recirculation of water and possible degradation of ground water.

Irrigation Return Flow

1. Continue research and evaluation of simulation modeling techniques in irrigated stream-aquifer areas. First results indicate that modeling can be used to predict the rates and direction and movement of contaminants in surface and ground water, and that in the future it may be possible to improve ground-water quality or limit salin-

Table 47. PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION AND THE PRIORITY FOR ADDITIONAL RESEARCH AND CONTROL IN THE NORTHWEST.

Sources	Research	Control
Septic systems	I	I
Sewage treatment plant discharge	I	I
Irrigation return flow	I	I
Dryland farming	I	I
Abandoned oil wells and test wells	II	I
Brine injection	II	I
Disposal wells	II	I
Surface impoundments	II	I
Mine drainage and mine tailings	I	I
Urban and industrial landfills	II	II
Radioactive waste disposal	III	II
Leaks and spills	II	II
Fertilizers and pesticides	II	I
Feedlots	II	II
Salt-water intrusion		
Coastal region	III	II
Inland region	I	I
Highway deicing salts	II	III
Mass burial of livestock	II	III

I - High
II - Moderate
III - Low

ity increases in rivers during low-flow periods.

Dryland Farming

1. Continue research on the relationship between dryland farming and saline seep occurrence.

2. Evaluate the present and future impact of saline seeps on ground-water and surface-water quality in the northern Great Plains states.

Abandoned Oil Wells and Test Wells

1. Enforce regulations requiring proper sealing and plugging of abandoned wells to prevent migration of fluids between formations and provide periodic field inspection of such operations.

2. File records of locations of abandoned oil wells, geologic and geophysical holes, together with relevant subsurface and construction details at state environmental agencies, to be available for consultation in the event of a contamination problem in a particular area.

3. Institute joint state and private industry programs for selecting abandoned wells for conversion to ground-water monitoring wells.

Brine Injection

1. Define the magnitude of the problem of ground-water quality deterioration from brine or waste-water injection by the petroleum industry.

Disposal Wells

1. Further investigate the impact on ground-water quality of discharge of excess irrigation water, storm runoff or liquid waste to shallow disposal wells in fresh-water aquifers.

2. Determine areas that are geologically and hydrologically suitable for deep-well disposal of liquid wastes.

Surface Impoundments

1. Evaluate in greater detail the impact on ground-water quality of the increasing practice of using surface impoundments for storage and treatment of liquid waste.

2. Prepare inventories of existing surface impoundments, obtain information on the character of materials being stored, and determine lining conditions and volumes of wastes discharged.

3. Assess hydrogeological conditions of each proposed, existing, and abandoned surface impoundment area to assess possible contamination of ground water.

4. Develop long-life impervious liners that are better able to withstand attack by impounded material.

Mine Drainage and Mine Tailings

1. Continue research into the feasibility of minimizing discharge from active and abandoned surface and deep mines.

2. Research the feasibility of sealing aquifer zones in coal strip-mining areas to prevent or reduce discharge of ground water to excavations and halt dewatering of aquifers.

3. Inventory baseline surface and ground-water quality, and determine the impact on ground-water and surface-water resources prior to commencement of new mining operations.

4. Continue research into methods for minimizing leachate from mine tailings.

5. Evaluate the quantity and quality of water presently stored in abandoned mines for possible future use.

6. Determine the possible impact of sand and gravel and placer mining operations on ground-water quality.

Urban and Industrial Landfills

1. Prepare inventories of industrial and municipal landfills and review climatic and hydrogeologic conditions at each existing and planned landfill site to determine the possible threat to ground-water quality.

2. Enforce regulations prohibiting disposal of toxic wastes in landfills.

3. Research potential ground-water quality degradation from composted shredded solid waste, such as wood and food-processing waste disposed on the land surface.

Radioactive Waste Disposal

1. Continue research into simulation modeling of waste plumes and ultimate fate of radioactive waste fluids.

Leaks and Spills

1. Develop an improved reporting system of pollution accidents and abatement procedures on a state-wide level.

2. Evaluate soil and ground-water conditions along oil, gas and mining product pipelines to assess potential hazard from spills or pipeline breaks.

Fertilizers and Pesticides

1. Further research the fate of pollutants from application of fertilizers and pesticides in soil overlying recharge zones of regional aquifers.

2. Investigate the impact on ground-water quality from the use of liquid fertilizer siphons installed on irrigation wells.

Feedlots

1. Inventory feedlots and review hydrogeologic conditions at existing and planned feedlot sites to assess possible danger of ground-water contamination.

Salt-Water Intrusion

1. Continue investigation into defining those areas that are susceptible to salt-water intrusion in coastal and inland areas.

2. Investigate the need for legislation by state and local agencies to control well spacing and pumping rates in critical areas.

Highway Deicing Salts

1. Assess the importance of this source of contamination.

Mass Burial of Livestock

1. Assess the severity of this potential problem and the possible impact on ground-water quality.

APPENDICES

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SECTION VIII

APPENDIX A - GLOSSARY OF TERMS

Acre foot - A unit for measuring the volume of water. It is equal to the amount of water needed to cover one acre of land with water one foot deep.

Alluvium - Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, floodplains, and in fans at the base of mountain slopes.

Aquifer - A geologic formation, group of formations, or part of a formation that is water yielding.

Artesian - The occurrence of ground water under sufficient pressure to rise above the upper surface of the aquifer.

Artesian Aquifer - An aquifer overlain by a confining bed and containing water under artesian conditions.

Artificial Recharge - The addition of water to the ground-water reservoir by activities of man, such as irrigation, or spreading basins.

Base Flow - The fair-weather flow of streams, composed largely of ground-water discharge.

Biochemical Oxygen Demand (BOD)- The quantity of oxygen utilized primarily in the biochemical oxidation of organic matter in a specified time and at a specified temperature. The time and temperature are usually five days and 20°C.

Brackish Water - Water containing dissolved minerals in excess of acceptable potable water standards, but less than that of sea water.

Chemical Water Quality - The nature of water as determined by the concentration of chemical constituents.

Concentration - The weight of solute dissolved in a unit volume of solution.

Connate Water - Water that was deposited simultaneously with the sediments, and has not since then existed as surface water or as atmospheric moisture.

Consumptive Use - The quantity of water discharged to the atmosphere or incorporated in the products of vegetative growth or industrial processes.

Contamination - The degradation of natural water quality as a result of man's activities, to the extent that its usefulness is impaired.

Crystalline Rock - A general term for igneous and metamorphic rocks as opposed to sedimentary rocks.

Degradable - Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original. Also referred to as biodegradable.

Degradation of Water Quality - The act or process of reducing the level of water quality so as to impair its original usefulness.

Demineralization - The process of reducing the concentration of chemical constituents.

Domestic Well - A well which supplies water for the occupants of a single residence.

Drawdown - The lowering of the water table or piezometric surface caused by pumping or artesian flow.

Effluent - A waste liquid, in its natural state, or partially or completely treated that discharges into the environment.

Evapotranspiration - The combined processes of evaporation from land, water, and other surfaces, and transpiration by plants.

Feedlot - A relatively small, confined land area for raising and fattening cattle.

Floodplain - The flat ground along a stream course which is covered by water at flood stage.

Fluvial Sediment - Those deposits produced by stream or river action (see Alluvium).

Glacial Drift - Boulders, till, gravel, sand or clay transported by a glacier or its meltwater.

Ground Water - Water beneath the land surface that is under atmospheric or greater pressure - the water that enters wells and issues from springs.

Ground-Water Recharge - The natural processes by which water is added to a ground-water reservoir.

Ground-Water Reservoir - The earth materials and the intervening open spaces that contain ground water.

Half-life (Radioactive) - The time in which one-half of the atoms in a radioactive substance disintegrate.

Hard Water - Water with over 60 mg/l of hardness.

Hardness - A property of water caused by the presence of calcium and magnesium, which is reflected in the amount of soap necessary to form suds and incrustations in appliances and pipes when the water is heated. It is expressed as an equivalent amount of calcium carbonate.

Heavy Metals - Metallic elements with high molecular weights, generally toxic in low concentrations to plant and animal life. Examples are: mercury, chromium, cadmium, arsenic, and lead.

Igneous Rock - Rock formed by the solidification of molten material that originated within the earth.

Industrial Well - A well used for the supply of water utilized in an industrial process.

Infiltration - The flow of a liquid into soil or rock through pores or small openings.

Irrigation Return Flow - Irrigation water which is not consumed in evaporation or plant growth, and which returns to a surface stream or ground-water reservoir.

Lacustrine - Deposits which have accumulated in lakes or marshes.

Lagoon - A shallow pond, usually man-made, to treat municipal or industrial waste water.

Leachate - The liquid that has percolated through the soil or other medium and has extracted dissolved or suspended materials from it.

Metamorphic Rock - A rock which has been altered by heat or intense pressure, causing new minerals to be formed and new structures in the rock.

Metasedimentary Rock - A metamorphosed sedimentary rock.

Milligrams Per Liter - The weight in milligrams of any substance contained in one liter of liquid. Approximately equivalent to parts per million.

Mineralization - The natural process of accumulation of mineral elements and/or compounds in soil or water.

Natural Brines - A highly saturated solution of soluble minerals, usually found in rocks associated with salt deposits or as a result of sea water evaporation.

Natural Leaching - The removal by a solvent of the more soluble minerals in soil or rocks by percolating waters.

Nutrients - Compounds of nitrogen, phosphorous, and other elements essential for plant growth.

Outwash - Stratified glacial drift that is deposited by meltwater streams.

Perched Ground Water - An isolated body of ground water separated from the underlying main body of ground water by an unsaturated zone.

Percolation - Movement under hydrostatic pressure of water through interstices of rock or soil.

Permeability - A measure of the capacity of a porous medium to transmit fluid.

Pesticides - Chemical compounds used for the control of undesirable plants, animals, or insects. The term includes insecticides, herbicides, rodent poisons, nematode poisons, and fungicides.

Piezometric Surface - The surface defined by the levels to which water will rise in tightly cased wells. Also called potentiometric surface.

Plume - An area of contaminated ground water originating from a point source and influenced by such factors as the local ground-water flow pattern, density of pollutant, and character of the aquifer.

Point Source - A stationary source of ground-water pollution.

Pollutants - Substances that may become dissolved, suspended, absorbed or otherwise contained in water, and impair its usefulness.

Pollution - The degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired.

Porosity - The relative volume of the pore spaces between mineral grains in a rock as compared to the total rock volume.

Primary Treatment (Sewage) - The removal of larger solids by screening, and of more finely divided solids by sedimentation.

Production Well - A well from which ground water is obtained.

Public Supply Well - A well from which ground water is obtained serving more than one individual or household.

Salt-Water Intrusion (or Encroachment) - Movement of salty ground water so that it replaces fresh ground water.

Saturation, Zone of - The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmosphere.

Sedimentary Rock - Rocks formed by the accumulation of sediment.

Soft Water - Water containing 60 mg/l or less of hardness.

Sorption - A combination of adsorptive and other physiochemical interfacial forces that removes pollutants from solution and retains them on fine-grained materials. Sorption may include ion exchange and precipitation processes.

Specific Capacity - The rate of discharge of water from a well divided by the drawdown of the water level in it. Properly stated, it relates to the time of pumping.

Storage (Aquifer) - The volume of water held in the interstices of the rock.

Surface Water - That portion of water that appears on the land surface.

Transmissivity - The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Trona - A natural sodium sesquicarbonate and source of sodium compounds.

Unconsolidated Rocks - Uncemented or loosely coherent rocks.

Water Cycle - The complete cycle through which water passes; water vapor in the atmosphere, liquid and solid as precipitation as part of surface and ground water and eventually back to atmospheric vapor.

Water Quality - Pertaining to the chemical, physical and biological constituents found in water and its suitability for a particular purpose.

Water Table - That surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

Water-Table Aquifer - An aquifer containing water under water-table conditions.

SECTION VIII

APPENDIX B - WATER QUALITY STANDARDS

The levels of mineralization or contamination which can be tolerated in ground water are dependent upon the use intended for water. Recommended water-quality standards are available for agricultural, industrial, and public-supply needs. Certain chemical constituents can be tolerated through a wide range of concentrations without adverse effects even in stringent cases requiring excellent water quality, while other constituents can be acceptable only at minute levels or not at all. Clearly then, the water quality standards for any particular use are varied and in most cases well documented. It is evident that to list each and every guideline is beyond the scope of this report.

As mentioned in Section V, the allowable chemical limits for potable public water supplies for each state are generally similar to the standards of the U. S. Public Health Service. In some states, the chemical concentrations currently allowed are in the process of review. In the near future, some revisions in permissible levels of certain constituents will be adopted, and analyses of constituents not now listed may be required. The most recent standards established by the U. S. Public Health Service for water supply are presented in Table 48.

Table 48. U. S. PUBLIC HEALTH SERVICE CHEMICAL STANDARDS OF DRINKING WATER, 1962.

Category A - Maximum allowable concentrations where other more suitable supplies are, or can be made available:

Substance	Concentration in mg/l
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250
Copper (Cu)	1
Carbon Chloroform Extract (CCE)	0.2
Cyanide (CN)	0.01
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3) a)	45
Phenols	0.001
Sulfate (SO_4)	250
Total Dissolved Solids (TDS)	500
Zinc (Zn)	5

Category B - Maximum concentrations which shall constitute ground for outright rejection of the supply:

Substance	Concentration in mg/l
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Hexavalent) (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	0.6 to 1.7 b)
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

a) In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

b) Varies with water temperature.

SECTION VIII

APPENDIX C - CONSTANTS AND CONVERSION FACTORS

Volume

1 gallon (g) = 3.785 liters
3.785 x 10^{-3}m^3
1 cubic foot (cu ft) = 7.481 gal
28.32 liters
1 acre-foot (acre-ft) = 3.259 x 10^5 gal
1,234 m^3
1 liter (1) = 0.2642 gal
1,000 cm^3
1 cubic meter (cu m) = 264.2 gal
1,000 liters
1 cubic hectometer (cu hm) = 10^6m^3
1 barrel (oil) = 42 gal
1 million gallons = 3.069 acre-feet
3,785.4 m^3

Flow Rate

1 gallon per minute (gpm) = 0.0631 l/sec
5.42 m^3/day
1 million gallons per day (mgd) = 43.7 l/sec
3,785 m^3/day
1 billion gallons per day (bgd) = 3.785 hm^3/day
1 cubic foot per second (cfs) = 449 gpm
28.3 l/sec
1 acre-foot per day = 14.2 l/sec
1 liter per second (l/s) = 15.9 gpm
86.4 m^3/day
1 cubic meter per second (cu m/s) = 22.8 mgd
35.3 cfs
1 cubic meter per day (cu m/d) = 0.183 gpm
1 cubic hectometer per day (cu hm/d) = 264.2 mgd

Pressure

1 pound per square inch (psi) = 0.07031 kg/cm^2
1 kilogram per square centimeter (kg sq cm) = 14.22 lb/in^2

Transmissivity

1 sq m/day = 80.5 gpd/ft

Length

1 inch (in) = 2.54 cm
1 foot (ft) = 30.48 cm
1 mile (mi) = 1.609 km
1 centimeter (cm) = 0.3937 in
10 mm
1 meter (m) = 39.37 in
3.2808 ft
100 cm
1 kilometer (km) = 0.621 mi
1,000 m
10 hm

Area

1 acre = 0.4047 hectare
1 square mile (sq mi) = 2.590 km^2
1 hectare (ha) = 2.471 acres
1 square kilometer (sq km) = 247.1 acres
0.3861 mi^2
100 hectares

Weight

1 pound (lb) = 0.4536 kg
1 short ton = 2,000 lb
0.9072 metric ton
1 metric ton = 1,000 kg
1 kilogram (kg) = 2.205 lb